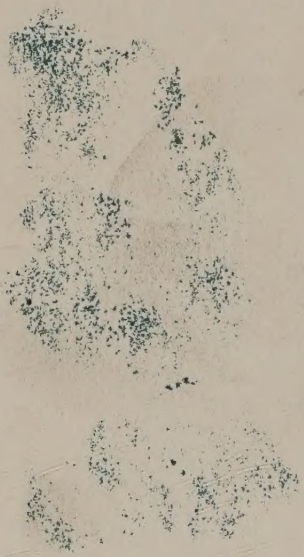
MIRACLES OF SCIENCE



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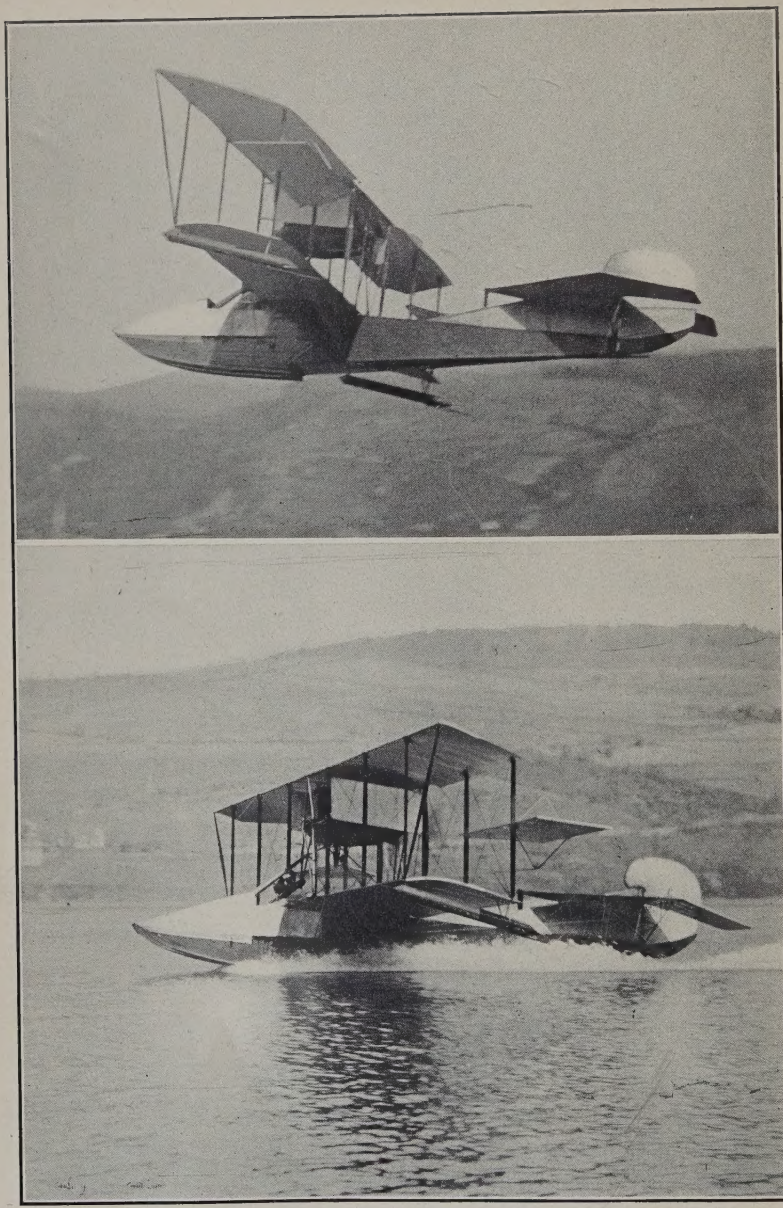

THE CURTISS HYDROAEROPLANE

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MIRACLES OF SCIENCE

BY
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ILLUSTRATED

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MIRACLES OF SCIENCE

INTRODUCTION

WE often hear it said that the age of miracles is past. This is a mistake. The age of miracles is the twentieth century. But the miracles that are now being performed are being done in accordance with verifiable—even though recondite—laws of Nature, and in the name of Science.

For example, consider the feat of weighing and measuring not merely our world but worlds that lie so remote from us in the far places of the universe that the light coming from them—though compassing space at the rate of 186,000 miles a second—requires a score of years to reach us. The astronomer not only weighs and measures these distant worlds, but he even tests their chemical composition almost as definitely as if he held some of their substance in his hand. And the chemicals that he tests are located so many billions of miles away that the mere figures that record their distance seem meaningless.

Surely this seems miraculous. It would be unbelievable if we did not know it to be true.

At the other end of the scale the physicist investigates the infinitely little. He makes visible with his

microscope specks that lie thousands of times beyond the naked-eye vision. Then he analyzes the smallest visible speck into billions of molecules; and dissects each molecule into its component atoms; and each atom into a miniature planetary system of perhaps 1,800 electrons. Billions of billions of these electrons could find lodgment on that disputed resting place for the feet of mediaeval angels—the point of a needle. Yet the physicist measures these unthinkably minute units of matter; weighs them; tests the speed of their flight and the quantity and quality of the electric charge they bear.

And this also seems miraculous,—nay *is* miraculous. It is surpassingly wonderful.

Again the biologist juggles with life in a way hitherto supposed impossible. He causes unfertilized germ cells to grow and develop. He splits the embryo of a living animal into two parts, four parts, eight parts, and produces two or four or eight living creatures from an egg that seemed predestined to produce but one. He cuts pieces of tissue from a dead chicken, puts them in his artificial incubator and causes them to take on new life.

If that does not savor of the miraculous, words must have changed their meanings.

These things, then, and their like are miracles of modern science. They differ from the fabled miracles of tradition in that they are not done in defiance of law, but in the investigation and interpretation of law. But they lead us so far beyond what formerly seemed the bounds of the possible that they almost challenge belief.

When the scientific worker does his miracle, however, he publishes his method, and another worker may follow him and duplicate his results. There are no esoteric methods, no secret processes, in the world of inductive science. Nor is there much that may not be interpreted in untechnical language and made of interest to the general reader without sacrifice of accuracy. Such an interpretation I shall endeavor to present in the ensuing pages, which will in effect take up the record where my *Story of Nineteenth Century Science* left it, and describe the progress of the past decade.

Every period of history is a transition period. The happenings of to-day grow out of the events of yesterday, and lead on to the developments of to-morrow. Arbitrary dividing lines, to mark off periods and epochs, are largely of man's creation.

Yet as we look back on the history of human progress, we see that great events tend to cluster. Certain generations seem to have been times of stasis; while other generations seem to vibrate with the energy of creative effort. Here and there a decade stands out as marking a turning point in human thought.

Such a vital, germinative epoch, I believe, is that with which we are here concerned. The first decade of the twentieth century will always be memorable as a time of great activity in the wide field of natural sciences, theoretical and applied. When the achievements of divers workers in this domain have been passed in review, it will be clear, I think, that the present epoch must take rank with the half dozen

or so great transition periods that are landmarks in the history of the growth of civilization.

Our first concern is with the new knowledge of the universe of which our solar system is an infinitesimal part, and with the wonderful implications of that knowledge. In subsequent chapters I shall review the progress of a decade in the fields of physics and chemistry, of biology and medicine, and of practical invention and the mechanical arts.

I

THE ORIGIN OF THE WORLD

CENTURY marks are of course only arbitrary divisions of time. But they enter so constantly into human calculations, that it is difficult not to regard them as actual mile-stones of progress. So it seems altogether fitting that a brand new explanation of the origin of the solar system should have been one of the earliest contributions to theory and knowledge at the beginning of the twentieth century.

It is a doubly auspicious augury that the idea should have come out of America—as the first great contribution to the theory of world-making that has originated in the western hemisphere.

The new theory found its origin, or at least its chief tangible support, in the observations of a famous American astronomer, Professor Keeler, then director of the Lick Observatory. This keen-eyed observer devoted the last two years of his life (1898-1900) to the special investigation of that curious member of the celestial family, the nebula. Working with the famous three-foot telescope known as the Crossley reflector, Keeler found that the universe is thickly tenanted with nebulae. He estimated that at least 120,000 of these bodies lay within the range of his vision as aided by the three-foot mirror. Several times that number are probably visible in the five-

foot reflector since then installed at the Mt. Wilson observatory.

Of course nebulae were no new discovery. A certain number of them had been observed since telescopes were invented. One or two are even faintly visible, like misty stars, to the naked eye. But the importance of Professor Keeler's observations consisted (1) in showing the vast abundance of these curious structures, and (2) in revealing the very striking fact that a large preponderance of the nebulae have a spiral structure. As the photographic film was made to supplement direct vision, revealing tenuosities of nebular structure that the eye cannot detect, it became increasingly evident that the spiral is, so to say, the typical form of nebulae as a class. And this suggested some highly interesting questions as to method of world building, as will appear in a moment.

Quite aside from their relation to world-making, however, these spiral nebulae are telescopic objects of peculiar picturesqueness. They seem to be great luminous whirlpools of incandescent matter. Perhaps to the average eye they suggest more than anything else the popular and familiar type of fireworks called the pin-wheel.

If you partially close your eyes and look at the photograph of a spiral nebula (a particularly good one is here reproduced) you can easily imagine that it represents a whirligig of fire, two revolving points making a pair of entwined incandescent spirals, and the sputtering flames sending out clouds of sparks and luminous smoke in an ever-widening circle.

Now in point of fact, something very like this is the interpretation which the astronomer puts upon the spiral nebula. He believes that its central luminous nucleus is an incandescent gaseous body like our sun, and that the two spirals that lead out from it, with their irregularly scattered foci of light, and their filmy veils of luminous smoke, represent matter that has burst forth from the central body, and that is now revolving about the central axis very much as the pin-wheel revolves about its central pin. Only of course the axis in this case is an imaginary body, like the axis of our sun or the earth's pole, and the span of the entire nebula is to be measured in unthinkable millions of miles.

There is a nebula in the constellation Andromeda that is estimated to be so wide that light requires at least eight years to span it. Its distance across is at least five hundred thousand times the earth's distance from the sun. It is faintly visible to the naked eye.

Regardless of size, however, what gives the spiral nebula interest from the present standpoint is the fact that nebulae have long been regarded as the matrix out of which solar systems such as ours are developed.

For about a hundred years astronomers had held as stock doctrine the theory of Laplace, according to which our solar system originated from a superheated gaseous globe which contracted as it cooled, and from time to time threw off rings of its equatorial substance that became planets.

But Professor Keeler's nebulae seemed to contradict this theory. The spiral nebula quite obviously

is not a uniformly gaseous mass. There is filmy, tenuous matter permeating its structure, but its main substance seems to be composed of more or less discrete nodules or nuclei.

THE SPIRAL NEBULA AS MOTHER OF WORLDS

Professor Keeler himself noted this discrepancy, but it remained for Professor T. C. Chamberlin, of the University of Chicago, and his younger colleague, Professor T. R. Moulton, to take the matter up, and to develop a new theory of world-making based on observation of the spiral nebula, but harmonized with all the new facts of astronomy and geology that had come to contradict the old hypothesis.

The new theory assumes that the typical spiral nebula, as revealed to us by the telescope, is in point of fact the parent structure of a solar system such as ours. Stated otherwise, it assumes that our solar system was once a spiral nebula differing only in size from any one of the hundreds of thousands of such bodies that still tenant the universe. It further assumes that the clustered masses to be seen here and there along the arms of the spiral nebula (knots in the skein, Professor Chamberlin has suggestively called them) are nuclei out of which will ultimately develop a group of planets more or less similar to those that constitute the sun's family.

A spiral nebula then, in this view, is a system of worlds in the making. The central nucleus is the future sun. Various of the spots that lie along the arms of the spiral are the nuclei of future planets. Professor Chamberlin calls nuclei of all sizes "plane-

A SPIRAL NEBULA

tesimals" because they are supposed to be revolving in independent orbits, like miniature planets. Hence the name "planetesimal theory."

It is obvious at a glance that the larger nuclei—bigger fragments of world stuff—make up the structure of the spiral arms. It should be explained that matter is not streaming along these arms as might be supposed, but that the entire structure is revolving as if it were a solid body. The larger nuclei, however, necessarily exert a gravitational influence over the smaller planetesimals in their neighborhood; hence an incessant shower of smaller particles will fall against each larger nucleus and this augments its size and its gravitational power.

As time goes on, each of these growing nuclei will (through gravitation) suck in the matter from the space about it, as a vacuum cleaner sucks in dust, until ultimately each larger body will be revolving in a clear space.

Thus the myriads of planetesimals will have been aggregated into a small number of planets; and the spiral nebula will have been developed into a planetary system. The original central nucleus of the nebula, having drawn to itself the cloud of minor planetesimals in its neighborhood, becomes a detached central sun.

According to this theory, then, our earth, in common with its sister planets, was never a gaseous ring, nor yet a liquid globe; but was built up about a more or less solid nucleus by a perpetual meteoric bombardment.

Larger planets of our system may have gathered

matter so rapidly, thanks to their greater gravitational power, as to superheat their substance to the stage of liquidity or gaseousness. Such is still the condition of Jupiter and Saturn, and probably also of Uranus and Neptune. But our earth and the other smaller planets were probably from the beginning solid in structure, though doubtless developing a high interior temperature, through impact and compression. Their growth would be decreasingly rapid as the outlying planetesimal matter within their sphere was more nearly exhausted. But their growth continues, in a minor degree, even now; for it is well known that the earth sweeps up something like a hundred million meteors each day,—these meteors being, supposedly, belated fragments of the original spiral nebula. Occasionally a larger fragment of world-stuff in the form of a giant meteorite falls into our atmosphere, and finds at last a resting place on the earth.

THE DISCONCERTING CONDUCT OF PHOEBE

"Give a dog a bad name and you soon hang it," says the old proverb. It seems to be much the same with a theory. Once you challenge it with a discordant fact or two, new evidence against it begins to crop up on every side. So it is not strange that just as Professors Chamberlin and Moulton were challenging the theory of Laplace, a very striking piece of evidence against the theory should have been brought to light from a quite unexpected quarter.

The new evidence was secured by another famous American astronomer, Professor W. H. Pickering. While examining a star photograph made at the ob-

servatory established by Harvard University at Araquipa in South America, Professor Pickering noticed a hitherto undescribed minute star lying in the neighborhood of the planet Saturn. He strongly suspected it of being a new satellite. But he had not the time to follow up the course of the little body at the moment, and it was not until 1904 that he rediscovered it, and by noting its shift of position from night to night, proved that it is really a far-outlying moon of Saturn.

To this new found niece of old Mother Earth, Professor Pickering gave the name of Phoebe.

Now Saturn was already known to be provided with an abundant family, eight moons having previously been recognized in addition to the unique system of rings. Therefore the advent of this ninth satellite would not have created any great sensation in the astronomical world had it not been made evident that Phoebe is behaving in a most anomalous manner. Not only has she taken up her position at a vast distance from her parent orb, but she is actually revolving in opposite direction to the direction of rotation of Saturn and the orbits of revolution of all the other moons. A tenth moon discovered still more recently by Professor Pickering is following the accepted course; so Phoebe's eccentric conduct is all the more emphasized.

It will be recalled that according to the hypothesis of Laplace each satellite has been spun off from the equatorial belt of its parent planet, and hence must obviously go on revolving in the direction of the parent body's rotation. Our moon follows this rule; so

do the four moons of Mars, the five moons of Jupiter that were then known, and the eight previously known satellites of Saturn. The rings of Saturn had also been proved to spin about in the same way; indeed, the system of Saturn had often been pointed to as in itself presenting what might almost be called a working model of the Laplacian hypothesis of worlds in the making.

And now came this ninth satellite, like a broken cog in the wheel, to interfere with the harmonious arrangement of this pleasing mechanism. Phoebe is but an inconsequential body as to mere size. And she is so distant from us that, as Professor Poor estimates, to see her at all puts a test on our telescopes equivalent to what would be required if one were to stand in New York and attempt to watch a humming bird flitting about the flower beds in the garden of the Capitol at Washington.

Yet this one tiny satellite moving in reverse order seemed to disprove the entire theory as to the origin of worlds.

For, be it understood, exceptions do not prove rules in the scientific world—they disprove them. This single refractory little satellite would upset the nebular hypothesis more convincingly than all Professor Chamberlin's reasoning,—unless a way could be found to explain its anomalous conduct.

HAS THE WORLD TURNED UPSIDE DOWN?

But mathematicians are resourceful in sustaining accepted hypotheses, and of course the old theory was not to be given up without debate. More than one

explanation was put forward that might conceivably account for Phoebe's eccentricity. In particular Professor Pickering himself explained it picturesquely by assuming that Saturn had originally rotated in the reverse direction, but that subsequent to the detachment of the ninth satellite the planet had turned completely over owing to what is called the precessional effect of the sun's gravitational pull on its bulging equator, which acted as a sort of tidal brake.

You can illustrate the effect very clearly if you will experiment with a kind of top or gyroscope that whirls in so-called gimbal rings. This top will spin for a long time without changing its direction of axis if not interfered with. But if you touch your finger to its rim (tidal brake) you will cause it to twist to one side, and as you continue the pressure you will see the top turn completely over and remain there (the obstruction being removed) spinning in the opposite direction to that which it had at first.

This interesting theory of the overturning of the planets applies of course to other members of the system, including the earth. It finds partial support in the vertical revolution of the satellites of Uranus. But another complication was introduced when Professor Perrine in 1905 made photographic discovery of two new moons in the system of Jupiter (the sixth and seventh) which seemed to be revolving in almost the same orbit, but one of them going forward, the other (No. VII) in retrograde direction.

Even the turning upside down of planets cannot account for two moons revolving in *opposite* direction at about the same distance from their primary.

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And even if the seventh satellite of Jupiter should prove on further examination not to have a retrograde movement (the question is not quite settled) there would still remain such anomalies as the exceedingly rapid rotation of the innermost moon of Mars; the ever-puzzling fact that neither the sun itself nor any of the planets revolves fast enough to produce a centrifugal effect adequate to overcome the attraction of gravitation; and the vital fact that the planets do not revolve in the plane of the sun's equator.

Moreover Professor Moulton in 1909 carried out an elaborate mathematical investigation which seems to render it at least doubtful (1) whether a revolving gaseous body, such as the original Laplacian nebula is supposed to have been, could develop the mechanical conditions necessary to whirl off a ring of its substance, and (2) whether such a ring could assume the form of a planet even if it were detached.

THE PLANETESIMAL THEORY SOLVES MANY PUZZLES

The planetesimal theory, on the other hand, seems to afford a fairly satisfactory explanation of all the observed anomalies of planetary revolution and rotation, without doing violence to any recognized law of mechanics.

For example, the crucial facts that the sun rotates slowly and that the planets do not revolve in the plane of the sun's equator, present no difficulties, since neither the direction nor the speed of the sun's rotation is conceived as having had anything to do with the genesis of the planetary system. The sun merely continues to rotate—like the big top that it is—on the

same axis and with a good deal the same speed that it had before the explosive outburst occurred which produced the spiral nebula out of which the planets have developed.

The planets themselves, as they were built up about nuclei or masses in the spiral nebula, might at first have no motion of rotation, but would begin to rotate in response to the influence of impinging planetesimals.

Professor Moulton shows that the results of such impingement would be generally, but not necessarily, to give a forward rotation somewhat in the plane of revolution. But the presence of other large masses (future moons) near by may alter this; and there is no theoretical reason why any degree of aberration might not be observed. Thus the variously tipped axes of the planets are accounted for.

Again, outlying masses that were not at first part of a given planetary system might be brought within the influence of a forming planet at a relatively late stage (somewhat as Jupiter even now captures comets), and these captives might revolve in any plane or in any direction, just as comets do. So the retrograde revolution of Phoebe is explained; also the aberrent revolution of the moons of Uranus and Saturn. Likewise the speed of little Phobos, which races three times round Mars while that planet is revolving once. There is no restriction put upon the speed of a satellite by the rotation speed of its primary according to the new theory.

It may be added that Professor See of the Marine Observatory at Mare Island, California, has elaborat-

ed this capture theory, in particular with reference to the asteroids, which he thinks were drawn into their orbits by Jupiter. Our moon also he regards as a capture product. Its curiously marked face, he thinks, shows the effect of the impact of asteroids as it came through their zone. Each lunar crater, in his view, marks the tomb of a planetoid, and not the location of a former volcano.

The planetoids themselves, by the way, were always stumbling blocks to the Laplacian hypothesis. In the new view they are simply largish planetesimals that did not chance to lie near a larger nucleus of condensation and hence have remained isolated, like myriads of the yet smaller fragments we call meteorites.

In a word, then, the planetesimal theory seems to have a high degree of probability. It is easily the most plausible hypothesis of the origin of the solar system that has ever been advanced. It is peculiarly hospitable to various interpretations as to details of progression in world-making. No known fact of astronomy or mechanics contradicts it vitally; a multitude of facts support it.

Of course it is not utterly nugatory of all that went before. We have seen that the new theory, like the old, conceives the solar system to have originated from a nebula,—it is still a "nebular" hypothesis. But the entire change of view that it contemplates in regard both to the original state of the nebula and the stages of evolution through which a planetary system is evolved, is so radical that the theory is fully entitled to be regarded not only as novel but in a sense as revolutionary. It extends to the planetary system in

detail the principles of world-building made familiar through Lockyer's famous meteoric theory of sidereal cosmogony.

THE ORIGIN OF SPIRAL NEBULAE

If, then, we give at least provisional recognition to the spiral nebula as the "Mother of Worlds," a question naturally arises as to how this interesting structure itself came into being.

Professor Moulton answers this question in detail. He tells us that what we now view as a spiral nebula was aforetime (let us say a million or a hundred million years ago) a gaseous star, not particularly different from millions of others that exist in the sky to-day, or for that matter from our sun itself.

But it chanced that in its progress through space this star flew in a direction which brought it ultimately in the neighborhood of another star. Unless the scheme of the universe is something quite different from what we now imagine, this must happen in course of time to every stellar body. All the stars are moving, and their rate of speed in some measured instances exceeds 100 miles per second. They are moving in different directions, in groups, clusters, pairs, or singly, and it would seem inevitable that their paths must cross.

It will not often happen, in all probability, that two stars will meet head on. But they may exert a tremendous mutual influence without actually colliding. A German astronomer named Roche made, half a century ago, a famous estimate to the effect that if two stellar bodies of equal size approach each other

within a distance of about two and a half radii, the power of gravitation will suffice to tear the structure of both bodies asunder.

To make the illustration specific, if a body as large as the earth were to come within something less than 10,000 miles of the earth, both our globe and the other body would explode like bombs and their fragments would be scattered out into space. This critical distance of two and a half radii (more exactly 2.44) is known to astronomers as Roche's limit. Saturn's rings lie within this limit, and seemingly illustrate the law, as they consist of comminuted particles of world-stuff.

But suppose now that two stars hurtling through space approach each other at such an angle as not to come within the dangerous explosion zone (Roche's limit) but on the other hand near enough to exert a mutual tidal strain of tremendous power. Gigantic tides will then be raised on each of the bodies, and even though their structures as a whole are not disrupted, there will be a vast eruption of their gaseous substance from opposite sides of both bodies.

That the tidal effect should be manifested equally in opposite directions, is well understood by mathematicians. To the non-mathematical mind, the fact though puzzling is made familiar by the twice-daily recurrence of the ocean tides.

If we look closely at the photograph of a spiral nebula, we shall see that the two spiral arms do in point of fact originate exactly opposite each other in the structure of the globular central nucleus.

The eruptive mass which thus bursts forth with

explosive violence from each side of the star would stream straight out into space in opposite directions and each stream would ultimately fall directly back upon the body from which it came, as a ball drops back to the earth when you toss it into the air, were it not that the gravitational influence of the passing star, which caused the eruption, continues to make itself felt upon the erupted matter. The main eruption would occur just at the moment when the stars were nearest each other, minor eruptions would have taken place while the stars were approaching and will continue for some time as they recede. And all the matter both of major and minor eruptions will be drawn aside from a direct outward flight by the gravitation pull which shifts its direction constantly with the movement of the passing body.

The result will be, as Professor Moulton has demonstrated mathematically, that the two main eruptive streams will be drawn out to form independent spirals, the space between which will be more or less filled with matter from the minor eruptions; and that each particle of eruptive matter will ultimately settle into an elliptical course, for the most part permanently detached from the central nucleus. In other words, such a form as we see actually taken by the spiral nebula is fully accounted for.

WORLD SMASHING

Such, then, is the result when two stars approach each other without actual collision.

But it must occasionally happen that two members of the sidereal swarm, as they dash through space,

will come within the danger line of Roche's limit, or actually plunge together.

In either case the stars must explode like gigantic bombs, and it seems unlikely that the resulting nebular masses would take on the regular form of the nucleated spiral. We should rather expect the gaseous mass to assume a more or less globular form in case of explosion without actual contact; a cone-shaped mass if the two stars came together at a converging angle; or a long drawn out cloud in the event of a glancing head-on collision.

And in point of fact the telescope fully justifies these expectations. There are multitudes of nebulae that do assume forms widely different from the typical spiral.

There is a famous nebula in the constellation Sagitarrius, for example, which is called the trifid nebula because it seems to be split into three somewhat regular parts. Again there is the network nebula in the constellation Cygnus, which is drawn out into a long irregular curiously cloud-like streak of nebulosity; and there are sundry other nebulae that are disc-like in form, and a few that have the shape of rings,—notably one in the constellation Lyra which is visible through a small hand glass.

We cannot suppose that nebulae of these aberrent types will develop into solar systems such as ours. They seem destined to produce clusters of stars rather than a single star with small planetary attendants.

AN ALTERNATIVE THEORY OF THE FORMATION OF NEBULAE

Although the theory of collisions between stars gives a rather plausible explanation of the origin of

"NETWORK" NEBULA

nebulae, we must not overlook the fact that an alternative explanation has been put forward in recent years. This is Professor Svante Arrhenius' theory that the universe is full of "cosmical dust," thrown out under influence of the pressure of radiant energy from the incandescent stars. The electrified particles of world stuff driven off from the suns are supposed to collide in space and build up tiny meteorites, which ultimately aggregate under the influence of gravitation. Myriads of these meteorites fall into the earth's atmosphere; sundry swarms of them make up the wisps of matter we call comets; still greater swarms, out in sidereal space, build up the nebulae.

According to Arrhenius the nebulae thus constructed are cold with the frigidity of empty space, and owe their luminosity to the impact of electrified particles, causing a glow like that of the rarefied matter of a vacuum tube in the laboratory.

It is quite possible that both theories of nebular origins are correct. The spectroscope shows that nebulae are of two quite different types. Many of the filmy ones give a bright line spectrum characteristic of incandescent gases; whereas the spiral nebulae reveal a mixed spectrum, partly of condensed, and partly of gaseous matter, confirming thus their telescopic appearance.

THE ORIGIN OF WORLD-SYSTEMS

But whatever the origin of the nebulae, there is no difference of opinion as to the destiny of some at least of them. The mass of meteoric matter of which they are composed will ultimately condense to form

star clusters or world systems. Very recently, to be sure, the question has been raised as to whether some nebulae may not be in reality veritable universes of stars, lying far beyond the limits of our sidereal system, as was formerly supposed. But there are cases in which no such interpretation can be put upon the observed conditions; cases in which the process of star-formation seems to be directly revealed in a great modern telescope.

In the group of the Pleiades, familiarly known as the "little dipper," for example, such a process of star-formation may be clearly observed. To the naked eye and even to a telescope of considerable power, the main stars of this group (those that outline the dipper) appear as ordinary stars of the fifth or sixth magnitude. But in the great five-foot Mt. Wilson reflector, these stars seem to be surrounded by a misty veil of nebulous matter. In photographs of long exposure, shreds of the nebulous matter are seen to extend from one star to another. They leave no doubt that the divers stars are enmeshed in the same nebulous structure.

Here, then, we observe the later stages of development of nebular condensation; or, from the other point of view, the earlier stages of star-formation. Could we look ahead sundry millions of years, we should doubtless see the stars of the Pleiades shining as clear central points without a nimbus, each one having absorbed (through gravitation) the nebular matter that now surrounds it.

There is every reason to believe that numberless star groups in the heavens have had a similar origin.

There are indeed visible star groups to match each type of nebula,—roundish clusters within which thousands of stars are massed (there is a fine example in the constellation Hercules); conical groups; and groups having a linear arrangement like the familiar belt of Orion.

And as to groups comprising merely two or three stars relatively near together, they positively abound. Recent observation has shown that one star in seven becomes a visual double when viewed through the biggest telescope. Of stars of the Orion type one in three proves to be a double. Then there are multitudes of stars that are accompanied by dark companions, the presence of which is revealed only by the spectroscope.

THE LIFE-STORY OF A STAR

It would appear, then, that a star is a body which is born out of the cosmical mist of a nebula. The stages of stellar evolution are pretty clearly revealed by the spectroscope. The young star, it would appear, although it is incessantly giving out heat, nevertheless contracts so rapidly that it becomes hotter and hotter. Presently it shines with a dazzling white light, as illustrated by the well-known stars Sirius and Procyon, and a host of others. At this stage the spectrum reveals the presence of the light gases, hydrogen and helium.

Then the star cools somewhat and becomes yellowish in color; and the spectroscope shows the vapors of calcium, iron, and numerous other familiar terrestrial elements. Our sun is a star in the yellow stage; and

another familiar example is the bright star Arcturus.

At a still later stage the star becoming yet cooler takes on a reddish glow, and its spectrum shows characteristic bands of carbon. Betelgeuse and Mira are familiar examples.

The stages of this evolution require unthinkable billions of years, but there seems to be no escape from the conclusion that each and every star is destined ultimately to be blotted out in darkness,—reaching a condition, in other words, of which we have examples on a small scale in the present state of the moon and of the earth itself.

So far as present knowledge goes there is only one way in which a star that has thus become cold and dark can be rejuvenated, and that is by collision. There would seem to be no reason, however, why any given star might not undergo the process of collision, nebula formation, slow cooling, and extinction, over and over. During each time of brilliancy it would lose some of its substance and its energy through radiation; but on the other hand, new matter must come to it constantly in the form of cosmical dust; and renewed energy may be accumulated through momentum acquired in falling through space—say toward the gravitation center of the universe.

So the cyclic process might conceivably go on forever; or at all events until some unthinkably remote epoch of the future when all the gravitational matter in the universe has been aggregated into a single mass. Meantime it would seem as if the periods of darkness for each individual star must be indefinitely long in comparison with the periods of brightness.

This would imply that dark stars must be more numerous in the universe than bright ones.

INVISIBLE NEBULAE

And this suggests a query as to whether there may not also be non-luminous nebulae in the heavens. This seems probable enough; indeed the puzzling thing is rather that so many nebulae are visible. But until very recently no direct evidence of the existence of dark nebulae was forthcoming. Early in the present century, however, some novel observations were made which may be most plausibly explained on the supposition that a dark star had plunged directly through the mass of an invisible nebula.

If our inferences are correct, the catastrophe in question really occurred about the year 1600,—just at the time, let us say, when the Pilgrim Fathers were planning to migrate to America. But the colliding bodies lie so far distant in stellar space that the light waves with which the disaster was signaled forth required about 300 years to reach our planet. Thus it happened that one night in February, 1901, it was recorded in terrestrial observatories that a new star had flashed suddenly forth in the constellation Perseus. Night by night this star became brighter until it equaled stars of the first magnitude in brilliancy. Then it gradually faded away. In the course of a few months it became invisible to the naked eye, and in the succeeding years it has remained at about the twelfth magnitude, near the limits of vision of all but the largest telescopes.

But as the star diminished in brilliancy there was

observed to form about it a nebulous haze which spread rapidly outward in all directions until an oval nebula of large dimensions was formed. The rate of seeming growth of this nebula, spreading outward in all directions from the star, was comparable to the speed of light.

At first astronomers were at a loss to explain this curious phenomenon. If the blazing up of the new star had been due to the collision of two dark bodies, the incandescent mass formed would presumably blaze out as a permanent star, instead of fading quickly away. And if the seeming spread of the nebula marked an actual dispersion of gaseous or other matter, its rate of progression exceeded what had been believed to be the speed limit of particles of matter.

So the most plausible explanation of the phenomena seemed to be that a dark star in plunging through the body of a pre-existing nebula had been rendered incandescent at its surface only and hence quickly lost brilliancy after passing through the nebula; and that the seeming growth of the nebula month by month as viewed from the earth marked the spread of light which thus illuminated the pre-existing but hitherto dark nebula in due course from center to circumference. The size of the nebula may be judged from the fact that it required several months for the light to reach its borders,—and light travels, it will be recalled, 186,000 miles per second.

WHY NEBULAE ARE NUMEROUS

We must not take leave of the new star in Perseus without noting that a somewhat different explanation

PROFESSOR SVANTE ARRHENIUS IN HIS STUDY

of the curious phenomena involved has been given by the famous Swedish chemist and cosmologist Professor Svante Arrhenius. This profound student of cosmical conditions believes that the spread of a luminous nebulosity in the region of the new star really marked the dissipation through space of matter thrown out from the star. He thinks the light of the star itself due to the collision of two dark stellar bodies. The volumes of minute particles thus engendered were driven off, according to his theory, from the central body under the influence of the pressure of light. Hence they traveled at approximately the speed of light. The fading out of the star, he explains, is due to the obscuring of its light through the accumulation of clouds of this cosmical dust about it.

It should be understood that this explanation is in keeping with a general theory of the scattering of cosmical dust through the universe through the influence of light pressure, which Professor Arrhenius has elaborated and given a prominent place among recent speculations as to solar and sidereal physical conditions. On the whole, however, the theory of a dark body ploughing through a nebula is the more plausible explanation of the observed phenomena of the new star. On this assumption, the phenomena take on peculiar interest when we reflect that they seem to suggest that invisible nebulae may be scattered everywhere throughout stellar space. For aught we know to the contrary, our solar system may be darting directly into one of these great nets. The case of the new star in Perseus seems to show that

the nebulous matter may be sufficiently dense to bring the surface of a star to incandescence. That obviously would mean the annihilation of all life on the globe, even though the entire mechanism of the solar system were not disrupted.

We know that we are at present far removed from any one of the myriad of dark stars, else their presence would make itself known though a gravitational effect on the orbits of the planets. But it seems quite within the possibilities that a nebula might be spread out net-like in our course without revealing its presence until we were fairly enmeshed in its substance. The probability is not one to cause even the most timorous to lie awake of nights. But that it is a possibility,—and one that in the course of the ages will become a reality,—the observation of the new star in Perseus seems strongly to suggest.

Very likely the human race will be extinct before this happens. But in any event we cannot suppose that the snuffing out of life on a fifth rate planet such as ours, in connection with a minor solar system, can be of any conceivable consequence in the cosmic scheme of a universe of a hundred million or perhaps a thousand million suns. A fly on the window pane bears a larger relation to the size of our globe than the globe itself bears to the space compassed within the sphere of the visible stars.

II

CHARTING THE UNIVERSE

TO us its inhabitants our earth seems a very big place. The man who has been "round the world" has taken a journey that is to be remembered for a life time. The fastest express train requires four days to cross our big continent. The fastest ship takes five days to cross the narrowest part of the Atlantic.

Our modern air ships fly a mile a minute—sixty miles an hour. Suppose an airship were so perfected that it could maintain its flight uninterruptedly day after day without stopping for repairs or fuel. Such a flying machine, going a mile a minute, would carry its passengers clear around the world at the equator in less than seventeen days.

That would be a feat worth talking about,—the circumnavigation of our big world in little more than half a month.

But now suppose that the airmen, flying thus at uniform speed of a mile a minute, could start straight up into the air and could continue in a bee line on a Jules Verne voyage off into space. How long would it take him, think you, to get to our neighbor Mars? Why, a matter of ninety odd years.

That would be a tiresome voyage,—not to speak

of the absence of air and the frigidity of empty space. Yet it would constitute only the beginning of an exploratory tour across the solar system. If our phantom voyager were disposed to see something more of the world-system of which the earth and Mars are minor members, he might pass right on for some centuries through the region of the swarming minor planets, called asteroids or planetoids, and only after 700 years of flying would he come to Jupiter,—something really worth while in the way of planets, bulking 1300 times bigger than the earth.

Another period of 760 years would be required to cross the gap between Jupiter and Saturn. The journey from Saturn to Uranus would require 1700 years. And the final stage of the tour across the planetary system to Neptune, the farthest outlying member of the sun's family, would take 1800 years more. Thus the entire journey from the earth to Neptune (when that planet is nearest us) would require 5000 years.

If we recall that the craft which thus required fifty centuries to pass from our earth to its most distant planetary neighbor required but seventeen days to circumnavigate the earth itself, we shall pretty clearly realize that our solar system is a stupendous structure.

But all things are relative. And if we would fully grasp the situation, we must reflect that the journey to Neptune is after all only a very short excursion into the depths of space as contrasted with the stellar distances. If our hypothetical air-machine, which went to Mars in ninety years, and to Neptune in 5000,

could continue at unabated speed, fifty *million* years would be required for it to reach the nearest star.

That is to say, the star that is our nearest neighbor in space lies about 18,000 times as far away from us as the remotest member of the sun's planetary family. The trip to Neptune bears the same relation to the trip to the nearest star that a brisk half hour's walk here on the earth bears to the circumnavigation of the globe.

As to the stars that make up the main galaxies that greet our eyes whenever we glance skyward, it is futile to attempt to give a notion of their distances in terms of mundane measurements. To say that our mile-a-minute aeroplane would require a thousand million years to reach a star of average distance, and twenty or thirty billion years to come to the remoter stars of the galaxy, conveys little meaning, since millions and billions, however glibly phrased, are incomprehensible terms.

But whether or not such distances are comprehensible, they represent actual magnitudes with which the astronomer, when he charts the heavens, must deal as familiarly as the surveyor of land deals with rods and miles. To make his figures a little more manageable, the astronomer adopts a new unit of measurement. He estimates stellar distances in terms of "light-years;" the light-year being the distance that light, compassing 186,000 miles per second, travels in 365 days. This distance—the astronomer's foot rule—is almost six million million miles.

The nearest star is at a distance of about four light-years. The farthest stars revealed by the tele-

scope, are thousands of light-years away. Meantime light comes to us from the sun in eight minutes, and travels on to Neptune, the farthest member of the solar system, in five and a half hours.

Such estimates serve to give us at least a vague notion of stellar distances, and of our isolation in space. But most of all they make us wonder at the wizardry that has enabled the modern star-gazer to ferret out the secrets of bodies so unthinkably distant. It would almost appear as if the modern instruments had made distance a negligible quantity. And in point of fact it is true that the universe at large is the laboratory of the scientific investigator of our day.

Not content with analyzing terrestrial phenomena, he reaches out to the sun, to the farthest planets, then on across the abysmal spaces to the stars and nebulae. And he tests the physical properties and chemical composition of those infinitely distant bodies in a way that is weird and mystifying. He not only expands the limits of the visible universe to unbelievable dimensions, but he invades the domain of the invisible. He proves to us that there are myriads of dark stars out in space, and that in many cases these stars can be located, tested as to their flight, and actually weighed and measured.

Weirdly incomprehensible as these feats seem to the uninitiated,—and assuredly they do have attributes of the miraculous,—there is nothing occult or inexplicable about them. They are performed with instruments of definite and well-known types; instruments that differ from those in common use among scientific workers in general only in the exquisite

delicacy of their mechanism, not in their principles of action.

The big forty-inch refracting telescope of Yerkes Observatory, for example, is after all only an overgrown field glass. And the biggest reflecting telescope is merely a concave mirror, differing in no essential principle of action from the reflector made by Sir Isaac Newton two centuries ago. As to the remaining implements of the astronomer's essential equipment, the spectroscope was first used in star-testing by Huggins as long ago as 1862; and the utility of the photographic plate has been recognized for about the same period. So it is not so much new methods as the better use of old methods that accounts for the spectacular progress of present-day astronomy.

THE LIGHT-GATHERING TELESCOPE

The essential function performed by the telescope is the gathering of light and bringing it to a true focus. Obviously the larger the lens or mirror, the more light it gathers. But the matter of size is not everything, for the largest of all telescopes, Lord Ross' six-foot reflector, erected in Ireland in 1846, is no match for modern instruments; and the forty-nine-inch lens of the Paris refractor, the biggest thing of its type, has been used only for exhibition purposes. It is possible with the use of high power objectives to magnify the telescopic image almost indefinitely. The difficulty is that unless the lens or mirror is very perfect, and the atmosphere very clear, the image becomes only a misty blur. It is not

merely more light but better-focused light that the astronomer is forever seeking.

But suppose you combine size and quality; have your lens ground by an Alvan Clark, or your mirror fashioned by a Ritchie; substitute your metal mirror with a glass one superbly polished and thinly silvered on the front surface. Suppose, then, that you transfer your observatory from the heavy atmosphere of the sea-level to the thin, clear air of the mountain tops. Then conditions are achieved that bespeak notable results.

Such are the conditions under which work is done at Lick Observatory and at Mt. Wilson. As the case stands at the moment, the five-foot reflector at Mt. Wilson is effectively the most powerful instrument in existence, although as just noted it is not the largest. The hundred-inch mirror now in process of construction at Mt. Wilson will, it is hoped, surpass by yet another stage all previous efforts in the all-essential work of light-gathering.

The simplest test of a telescope is the capacity of the instrument to bring new galaxies of stars into the field of vision. At the outset we must recall that even our planetary neighbors Uranus and Neptune are invisible to the naked eye. So are all the little planets—about seven hundred are known—that people the space between Mars and Jupiter. The total number of stars within the range of unaided vision is only about five thousand. They are arbitrarily classified as representing six magnitudes of light.

But the telescope reveals galaxy on galaxy of otherwise invisible stars, the numbers increasing in

geometrical ratio with each decrease of magnitude. A one-inch glass shows stars of about the ninth magnitude, to the number of more than a million and a quarter. A three-inch glass opens up vistas that include twelfth magnitude stars. The twenty-five-inch lens shows sixteenth magnitude stars to the number of at least one hundred million; the forty-inch Yerkes lens brings to view yet remoter galaxies; and the five foot Mt. Wilson reflector records on the photographic plate, in myriads beyond all computing, stars estimated by Professor Pickering at the twentieth magnitude.

Newcomb computes that the telescope reveals stars 10,000 times fainter than the faintest to be seen with the naked eye. Ball tells us that the modern telescope "separates" double stars that are so near together that to see them double is equivalent to separating two candles less than two inches apart at a distance of forty miles.

THE WONDER-WORKING SPECTROSCOPE

And where the telescope fails us, the spectroscope takes up the work of extending the limits of the visible. This instrument, which consists essentially of a prism or a finely ruled grating which splits up a beam of white light into the primary colors, analyzes the light of distant stars (except the very most distant which are too faint with present telescopic powers) as readily as it analyzes the light of a hydrogen flame in the laboratory. It serves also to reveal any movement of a star in the line of sight. If the star is coming toward us the light waves are, as it

were, crowded together and thus its spectral lines are shifted toward the violet end of the spectrum; if it is receding, they are shifted toward the red end.

By measuring the shift of the spectral lines, the astronomer tests the speed of a star flight with marvelous accuracy. With the newest instruments, his range of error is scarcely greater than three-fifths of a mile per second in the case of bodies moving ten miles or fifty miles per second. He can even measure the speed of the earth in its orbit by noting the seeming approach and regression of a given star at half yearly intervals.

Or again by observing that the spectral lines of a certain star shift periodically back and forth regardless of the earth's movement, he is informed that the star in question is revolving in a mutual orbit with some other star. The spectroscope may thus "resolve" double stars that are far too close to be separated visibly in the most powerful telescope. Indeed, the star whose presence is thus demonstrated—the very size and weight of which may in some cases be estimated—may be a dark body that must forever remain invisible to all telescopic powers.

The spectroscope is, then, a chief instrument of the astronomer's equipment. The new science of astro-physics is the record of its revelations. The spectroscope as used by the astronomer has found its fullest development perhaps in the Mills spectrograph of the Lick Observatory, and the spectrographs in connection with the Snow telescope and the Tower telescopes of Mt. Wilson. An interesting and important modification of the instrument is Pro-

fessor Hale's spectroheliograph, with which wonderful photographs are made that reveal the location in different layers of the sun's atmosphere of hydrogen gas, calcium vapor, and other chemicals.

AIDS TO VISION SUPPLIED BY PHOTOGRAPHY

The photographic plate had proved in recent years almost as important an accessory as the spectroscope. It reveals and charts with accuracy myriads of invisible stars. It co-operates with the spectroscope by making a permanent record of the tell-tale lines which that instrument dissects out of a beam of light.

So important, indeed, is the photographic plate, that it largely takes the place of the human eye in direct observation of the heavens. Prof. W. W. Campbell says that a six-inch telescope and a photographic plate will measure the velocities of stars that could not be tested by the eye alone with the great 36-inch lens of the Lick Observatory. The 32-inch lens of the Potsdam Observatory is designed exclusively for photographic work, and not for direct vision. No lens brings all the rays of light quite to the same focus, and the rays that are best for photographic purposes are not those best for direct vision. So a selection must be made. This does not apply, however, to the reflecting telescope, the mirror of which may be made to bring all the rays to an accurate focus.

The task of taking photographs with these large telescopes is an exceedingly delicate one. Sometimes the negative must be exposed for many hours or even on successive nights, and it is necessary to keep the

telescope aimed with the utmost accuracy. This is effected with the aid of a small direct-vision telescope with two spider webs crossed in the field of vision. The task of the observer is to keep a certain star just at the juncture of the cobwebs. It is precisely the same method by which a gunner aims the gigantic cannon on a modern battleship. But the astronomer's task must be kept up for hours together. Moreover it is necessary occasionally to remove the plate and refocus the instrument, to make allowance for changes in temperature.

The net result, however, in the hands of such an expert as Professor Ritchie, is to produce, with the five-foot reflector at Mt. Wilson, photographs showing myriads of stars never hitherto revealed. It shows also the presence of unpredicted nebulosities in connection with certain stars. But, except for such nebulosities, the brightest and faintest stars alike are revealed only as points of light even by this most powerful of telescopes.

The chief value of the star photographs, as at present studied, is not so much dependent on the revelations of the myriads of fainter stars, as upon the accurate charting of the positions of stars that are nearer. Practically all recent additions to our knowledge of the motions of the stars have been made through study of the photographic plates. Indeed, the modern astronomer is much more likely to be found comparing photographic negatives in his laboratory than scanning the skies through a telescope.

Doubtless the most interesting things revealed by the modern observations of the stars relate to the

movements of those supposedly "fixed" bodies. The seeming fixity of the stars is merely due to their distance. In point of fact they are flying through space, singly, in pairs, in groups, clusters, and swarms, or in vast streams of incomprehensible magnitude. Some of them move upward of 150 miles per second; and the average speed of the very large number hitherto tested, according to Professor W. W. Campbell of Lick Observatory, is 20.2 miles per second. Our particular star, the sun, with his attendant planets, moves through space at the rate of about twelve and a half miles per second, making therefore in point of speed, as in the matter of size, a rather poor showing;—yet after all shifting our position in space by about 367,000,000 miles each year.

THE FLIGHT OF SUN AND STARS

Nothing perhaps shows the wizardry of the modern astronomer to better advantage than his revelations regarding this matter of the movements of the stars. To appreciate the complexity of the problem, we must reflect that the mundane observatory shifts its position in virtue of the earth's rotation by something like a thousand miles an hour; that the earth wabbles as it whirls and plunges through space at the rate of about nineteen miles per second in order to compass its annual journey about the sun, while at the same time being carried in yet another direction at twelve and a half miles per second by the translational motion of the entire solar system. The net result is that the actual course described in space by the earth is a zigzag spiral, to attempt to conceive

which in its entirety involves the non-mathematical mind in hopeless tangles. But it will be obvious that any observations of the seeming movements of stellar objects viewed from the earth must be checked and interpreted in the light of the actual movements of the earth itself, else they would be almost as hopelessly faulty as was the primitive conception that the sun and stars revolve about us.

Notwithstanding the complexities of the problem, the modern astronomer has been able to gain some tolerably clear notions as to the movements of the million or so of stars that lie nearest us in space. The more distant galaxies, to be sure, show no shift whatever in position, so far as present observations go; but this fact has its advantages, inasmuch as the faint objects in the background supply fixed points of comparison, which alone make possible the demonstration of the movements of the nearer stars.

It will be obvious from what has just been said as to the movements of the earth itself that the apparent movement of such stars as are near enough to reveal any shift of position at all will be of sundry types. As the solar system drifts forward through space at the rate of twelve and a half miles per second, the nearer stars will seem year by year to drift backward as compared with distant stars, just as nearby objects viewed from a car window seem to move backward. Meantime this backward drift will be complicated by the actual movements in different directions of the stars themselves. A star may, for example, be moving so rapidly in a course parallel to ours that it shows a forward instead of a backward

drift, just as another railroad train may pass ours even when we are going at best speed. Or the star may be moving at an angle to our line of flight, and hence the direction of its backward drift may be angular.

TESTING PROPER MOTION

Ignoring for the moment complications due to the actual motion of the stars, it will be obvious that, generally speaking, the backward drift—the astronomer calls it "proper motion"—will be greatest in case of the nearest stars and relatively less as stars become more and more distant. It is equally obvious that, inasmuch as the earth goes forward by about 367,000,000 miles in a year, the backward drift or proper motion of the stars should be very conspicuous, unless the stars are infinitely distant. But we have already seen that the stars *are* exceedingly distant; and perhaps nothing brings their aloofness more vividly to our comprehension than to be told that the shift in position of even the very nearest stars is so slight year by year that it would not change the naked-eye aspect of the heavens appreciably in a thousand years, although the earth has gone forward uninterruptedly at a speed of 45,000 miles an hour during the entire period.

But of course shifts in position that are quite inappreciable to the naked eye are magnified by the telescope to measureable and even conspicuous dimensions. So changes that would not be noted by the naked eye in a century or a millenium may be recorded by the telescope even year by year. More-

over, there are exceptional stars the apparent motion of which is notable. Thus there is an eighth magnitude star, detected by Professor Kapteyn in the photographic charts taken at the Cape of Good Hope, which seems to move by an amount representing 8.7 seconds of arc per year; a shift that would carry it across an apparent distance equal to the diameter of the full moon in two centuries.

With changes such as these the astronomer deals readily enough; yet we must reflect that the annual change in position of this most rapidly moving star is equivalent to a shift of only one foot in an object viewed at a distance of four and a half miles. Furthermore there is no other star known to move anything like as fast as this; and there are only sixteen stars all told that change position one-third as fast. The only one of these that is visible to the naked eye is the famous star Alpha Centauri, our nearest neighbor, which appears at second magnitude, and which would shift position across the face of the moon in about five hundred years.

DIRECTION OF THE SUN'S FLIGHT

A fractional part of such a movement as this suffices, however, for the tests of the astronomer; and as comparison of the present-day positions of the stars may be made with certain accurate star charts of earlier generations (notably that of Bradley made about the middle of the eighteenth century), the astronomer of our day can show the exact direction of backward drift or proper motion of a very large number of stars. Photographic plates taken at in-

tervals of years reveal these shifts of position even more tangibly; particularly when two photographs are viewed through a binocular apparatus, as the stars that have changed position then seem to stand out of the picture.

In so far as the changed position is due to the backward drift of which we are speaking, it is obvious that the projected lines of seeming motion of various stars will converge, like the rails of a car track, to a vanishing point that marks the antapex of the sun's flight. In this way we gain a pretty clear notion as to the direction of movement of the sun relatively to the other stars. It appears that we are moving almost directly away from the present position of Sirius, the brightest star in the heavens; and that we are aiming at a point which chances to lie about fifteen degrees southwest of the well-known bright star Vega in the constellation Lyra.

Sirius is brilliant in the southeastern sky, while Vega is only less conspicuous in the northwest, on any clear night in winter; so the most casual observer may gain a fairly clear notion as to the general direction of our flight through space.

It may be of interest to add that Vega is coming toward us almost as fast as we are moving toward him, so that each night we are nearer to him by about 2,000,000 miles than we were the night before. But as some thirty light-years of space separate us, the time when we shall meet is not to be scheduled among events of the near future. And even as they pass each other, it appears that the two stars will not be near enough together for appreciable mutual effect. This

is fortunate for our system as Vega is a hundred times brighter than our sun.

MEASURING STAR DISTANCES AND SPEEDS

It will be obvious that the amount of proper motion or backward drift of a star gives us at least a general notion of the distance of the star. A more accurate determination of the distances, however, may be made by viewing the star from exactly opposite sides of the earth's orbit, and thus utilizing the intervening space of 186,000,000 miles as a base line, somewhat as the surveyor utilizes base lines of carefully measured length in his triangles. It is obvious that the shift of position of a star due to its being viewed from opposite sides of the earth's orbit will be oscillatory in character, as contrasted with background stars that show no change of position.

It is also obvious that the amount of this shift will be much smaller than the annual proper motion, since the sun's flight carries us over an annual distance almost double the diameter of the earth's orbit; nor can we magnify the result by taking observations at intervals of years as in the other case. It follows that the oscillation due to the sun's annual revolution is so slight, even in the case of the very nearest stars, as to be exceedingly difficult of detection. For the vast body even of the stars that have proper motion it is entirely beyond reach of observation with any existing instruments.

When this semi-annual oscillatory shift can be detected, however, it affords the most accurate means of determining the exact distance of a star.

This test is called measuring the star's parallax. The test is made by noting the position of a star in relation to other stars, preferably by photography at intervals of just six months. For purposes of comparison, some astronomers prefer to take successive negatives on the same plate, a method introduced by Professor Kapteyn. Three exposures are necessary at intervals of six months, that allowance may be made for the earth's progressive motion as well as for its orbital swing. The delicacy of the test will be appreciated when it is stated that the half-yearly shift of position of the star that is our nearest neighbor in space is only three-quarters of a second of arc. Reduced to comprehensible terms, this is equivalent to a shift of position of about one inch in an object at a distance of five miles. Only seventeen stars are known to have a parallax exceeding about one-fourth this amount. To test such minute changes, the largest telescopes are needed; the Lick refractor with its sixty-foot barrel being peculiarly effective.

Professor Eddington, of the Royal Observatory of England, has recently pointed out that there is a good deal of uncertainty about the precise value of the parallax in the case of a good many of the stars that have been tested. But it gives us an illuminating sense of the marvelous accuracy of modern measurements to note his interpretation of "uncertainty" in the present sense. He explains that the measurements in a good many cases may be wrong by a matter of five-hundredths of a second, which represents a variation of three-fifths of an inch at forty miles distance. Meanwhile he assures us that

the repeated measurements of the nearest star are so in accord that we may confidently assume that they are accurate within one-tenth of a second.

And this is the equivalent of one-eighth of an inch at forty miles.

If we reduce the results of this measurement to figures, it appears that the distance of the nearest star (it is called Alpha Centauri) is nearly 26,000,000,000,000 miles—with a latitude, as Professor H. B. Curtis of Lick Observatory cautions us, of perhaps two hundred billion miles for errors or inaccuracy of observation. But this star is very neighborly indeed; for the next nearest is twice as far away, and the generality of the measured stars are forty or fifty times as distant.

Meantime it must be understood that only a very small company of stars are near enough to show any parallax whatever, even under the magnifying powers of the most powerful existing telescopes. With these few hundred exceptions, the vast myriads of stars that sprinkle the photographic plate like dust, show no discernible change of position when viewed from the opposite ends of our 186,000,000 mile base line.

Of course telescope and photographic plate, however perfected, can tell only of shift of position across the line of sight. A star might be coming directly toward us or receding directly for an indefinite period without shifting its position on the photographic plate. But here, as we have seen, the spectroscope steps in to record "line of sight" motion in either direction.

It makes no difference at all that the star may

be so distant from the earth that the light coming from it at the rate of about 186,000 miles per second has required many years to reach us. So it is possible to measure the radial speed of multitudes of stars that are too distant to show any parallax or to have their shift of position across the line of sight observed even by the most delicate methods. For many years Professor W. W. Campbell, Director of the Lick Observatory, devoted a large amount of time to testing the speeds of stars with the famous Mills spectrograph. In 1911 he was able to generalize his results, and to show that the large number of stars observed, when tested by their speed, tend to fall into interesting and suggestive groups. There were some complications and seeming inconsistencies, as there usually are when human observation of complex facts is in question, but, viewing the data as a whole, this highly interesting and utterly unexpected generalization seems to stand forth: "The older a star is, the quicker it moves."

It had long been known that there is great variation in the speed of stars. Our sun, for example, with its planetary attendants, is moving through space at the rate of 12 or 13 miles a second; whereas there are stars that are observed to move upward of 200 miles a second. But hitherto there had been nothing to suggest that the difference in speed was in any wise related to the age of the stellar body. Therefore Professor Campbell's observations came as an entire surprise to the astronomical world. A new coign of vantage, so to speak, was supplied from which to gain a glimpse into that great ultimate

problem as to the origin and destiny of the universe which persistently thrusts itself upon the attention of every speculative mind.

WHY DO OLD STARS MOVE RAPIDLY?

In Professor Campbell's own words "that stellar velocities should be functions of spectral types (i.e., should vary with the age of the star) is one of the most surprising results of the recent studies in stellar motions, for we naturally think of all matter as equally old gravitationally. Why should not the materials comprising a nebula [nacent star] or a class B [comparatively young] star have been acted on as long and as effectively as the materials in the class M [very old] star?"

The rigidly scientific cast of Professor Campbell's mind prevents him from attempting to give a decisive and final answer to this question. But, on the other hand, it does not prevent him from suggesting a scientific interpretation; only he is careful to avoid all appearance of dogmatism—even going to the length of putting his explanations in the form of question.

Let me again quote his words: "The established fact of increasing stellar velocities with increasing ages suggests the questions: Are stellar materials in the ante-stellar state subject to Newton's law of gravitation? Do these materials exist in forms so finely divided that repulsion under radiation pressure more or less closely balances gravitational attraction? Does gravity become effective only after the processes of combination are well under way?"

Notwithstanding the interrogative form in which this explanation is put forward, we are perhaps fully justified in assuming that Professor Campbell's question marks are only the shield—I had almost said subterfuge—with which an ultra-scientific mind often tends to protect itself against the charge of hasty generalizing. In point of fact, the explanation suggested in his questions seems not only an altogether valid interpretation of observed phenomena, but constitutes perhaps the only plausible explanation that could be suggested consistently with our present knowledge.

Yet to any reader who has not kept closely in touch with recent advances in physical science, the explanation must seem altogether startling. To suggest that there are forms of matter not subject to Newton's law of gravitation would have seemed to the physicist of even a dozen years ago a most heretical and unjustifiable assault upon the most fundamental of physical laws. Ever since Newton propounded his thesis that every particle of matter in the universe attracts every other particle with a force inversely as the square of distance between the particles and directly as the product of their masses, this "law," which seemed to explain all the motions of the planetary bodies and the revolutions of double stars no less than the fall of bodies at the earth's surface, has been the very corner-stone of physical science.

Yet Professor Campbell suggests that there is a stage of stellar development at which matter seems not to be subject to this law.

But lest the uninitiated suppose that this suggestion is altogether anarchistic, let me hasten to add that Professor Campbell does not mean to imply quite what his words seem to suggest. He does not for a moment suppose that there was ever a time when Newton's law of gravitation was not operative; he means only that there may be conditions under which its action is overcome by antagonistic forces.

When you throw a pebble into the air, you momentarily annul the power of gravitation over that stone. But even while the pebble is flying straight upward, in seeming defiance of gravity, it is being acted on just as definitely and just as vigorously by the gravitation pull as before; only the force of propulsion given by your arm-thrust masks and for the moment overbalances that resistant downward pull.

LIGHT PRESSURE AS A COSMIC FORCE

And so it is, according to Professor Campbell's suggested hypothesis, with the materials that make up the nebulous mass, which, according to the best modern notions of the astronomer, constitutes the first stage of star-development. The reader who has not viewed a nebula through a telescope has doubtless seen reproductions of photographs of nebulae, or at any rate of a comet, the tail of which is a nebula in miniature. It will be recalled, therefore, that a nebula seems to be made up of very fine particles of matter. Professor Campbell suggests that these particles of matter are so subject to "radiation pressure" that their tendency to gravitation toward other bodies is for the moment overcome.

Now "radiation pressure," being interpreted, means the pressure of light. The most familiar and striking evidence of the efficiency of this force—the existence of which has only quite recently been revealed to the physicist—is furnished by the tail of a comet, which, according to the most recent and most generally accepted explanation, consists simply of fine particles of matter driven off from the body of the comet, itself a more or less nebulous mass, by the "radiation pressure" of sunlight. The familiar observation that the tail of the comet always points away from the sun gives obvious support to this hypothesis.

Professor Campbell's suggestion, then, amounts to this: That a nebula consists wholly or in part of finely divided particles of matter which are thrust hither and yon in seeming defiance of the laws of gravitation, by the light-pressure of myriads of incandescent stars. In due course, however, the fine particles of matter become aggregated—say through collision—and thus become too large for the light-waves to act on them effectively;—for, be it understood, "radiation pressure" can oppose gravitation effectively only when acting on very minute particles; somewhat as a man can oppose it by hurling upward pebbles but not boulders.

So when the nebulous particles have sufficiently aggregated they begin to fall together, under the influence of gravitation, presently becoming so concentrated as to form the more or less solid body that we call a star. Thenceforth this body, undergoing a series of internal transformations which cause the

astronomer to label it a star of class B, C, D, etc., must move in response to the aggregate gravitation pull of the stellar bodies that make up the universe. In effect it must fall (so it would seem) toward the gravitation-center of the universe, and as time goes on it will gather speed in its fall, just as a body directed from a height gathers speed in falling toward the earth's surface. The older the star, then, the greater its momentum—which brings us back to the matter of fact of Professor Campbell's observations.

If the reader's imagination leads him to ask whether there is any limit to the ultimate speed attainable, the answer would seem to be that, sooner or later, the flying star will come into collision with some other flying star; when the two bodies, by mutual impact, will be reduced once more to the original nebulous state;—their speed thus retarded; their direction of flight altered; their particles momentarily dissipated; their cycle of world-development ending in a new beginning.

This imagined culmination, it should be explained, is no part of the generalization from Professor Campbell's observations, but a conclusion warranted by other lines of astronomical research.

OUR SUN AND ITS NEIGHBORS

All these varied observations imply that our solar system is isolated in space, separated from the nearest neighboring stars by unthinkable distances. Yet we must recall that in the astronomical sense our sun is itself a star closely similar to millions of others.

Nor can we suppose that in the cosmic scheme it is an important member of the galaxy. Certainly if size and brilliancy are to be taken as tests of importance, our sun makes but a mediocre showing.

Take for example, by way of illustration, a computation made recently by the Dutch astronomer Professor Kapteyn. He estimates that of the million and a quarter stars visible with a hand glass having a one-inch lens, there are about 27 stars that are from 1,000 to 100,000 times as bright as the sun; there are 1300 others that are more than a hundred times as bright as the sun; 22,000 that are more than ten times as bright; and 140,000 that match the sun or do not greatly exceed him. Thus, of our relatively near neighbors (using terms now in an astronomical sense) there are at least 100,000 stars which if brought as near to us as the sun would quite outshine him, some of them outmatching him thousands of times over. But on the other hand within the same radius of distance there are more than a million other stars that must be classed as less bright than the sun;—half a million of them very much less bright. So on the whole we may feel that our luminary is a fairly representative star, though distinctly nothing to boast of.

It will be understood that this computation of Professor Kapteyn's has to do only with a comparatively small number of stars lying relatively near to us. Specifically the stars in question are those that lie within a distance of about 560 light-years,—that is to say the distance that light would travel in 560 years. When we reflect that light travels 186,000 miles per second, it will be clear that the distances contemplated

are to be translated into unthinkable trillions and quadrillions of miles. Professor Campbell's studies show, however, that stars of different types are variously grouped in the universe as regards their average distances from the earth. He found, for example, that the very young stars on his list show an average distance of 534 light-years; whereas stars of the types most like our sun (F and G stars of his catalogue) are on the average only 92 and 145 light years distant respectively. It would appear, then, that our sun is one of a great cluster of similar stars located relatively near together.

CLUSTERS, GROUPS, AND STREAMS OF STARS

If we view the galaxy of stars from yet another standpoint, asking what has been revealed as to the ultimate structure of the cosmic mechanism, we learn that a combination of methods, in the hands of many observers, has given some extraordinary glimpses into the arrangement of at least those portions of the universe that lie somewhat within our neighborhood.

Considering first our immediate environment in space, it appears that our sun, with its inconsequential planetary attendants, is one of a company of seventeen stars making up a rather compact cluster about ninety-five billion miles in diameter,—roughly one million times the earth's distance from the sun. Seven of these stars are doubles. Five of them are larger than the sun; yet all are comparatively small, the brightest being only forty-eight times brighter than the sun; whereas there are more distant stars in the sky that are ten thousand times more brilliant.

Going out beyond the confines of our immediate star cluster, we find various interesting groups at what might be called—gauging our mind to stellar magnitudes—moderate distances.

There is, for example, a neighborly cluster of forty stars in the constellation Taurus, between the Pleiades and the bright yellow star Aldebaran, that Professor Lewis Boss, of Albany, watched with tireless assiduity for many years, using the proper motions alone, and not the spectrographic method. By laborious calculations he removed one source of error after another, until finally he could assure us that the stars of the Taurus cluster are moving through space together in parallel lines at uniform speed, like a flock of birds. They are 120 light-years (800 million million miles) away; but they passed us at half that distance about 8,000 centuries ago,—though the cave man of the period seems to have left no record of the visit.

Then there is a cluster of seventeen helium stars in Perseus; and another cluster of thirteen stars in the Great Bear, which seem to lie in about the same plane,—each cluster pursuing its own independent way, apparently quite unaffected by other stars that may chance to have wandered into the same territory.

As to the Great Bear cluster, it is rather surprising to learn that of the seven conspicuous stars forming the "big dipper," five are moving uniformly in one direction and the other two with equal uniformity in quite another direction. The familiar figure of the "big dipper" is therefore in part an optical illusion which will not maintain its shape throughout future

ages. In due course the "pointers," for example, will cease to point to the pole star. But the pole itself is shifting as our little globe wabbles through space, so this does not greatly matter. Some 12,000 years from now Vega will be the pole star, and no pointers will be needed to indicate that brilliant object.

At far greater distances in space there are groups of stars of the Orion or helium type, which have a characteristic spectrum suggestive of a recent origin. These are sometimes grouped into luminous clouds, like the Pleiades and the diffused nebulosity in Orion. Some of these stars are enormously brilliant. Rigel in Orion, for example, shines at first magnitude. Were it no brighter than our sun it would appear only as a telescopic star of tenth magnitude.

But while these and sundry other relatively small groups of stars are pursuing their individual flights in one direction or another, their movements—gigantic though they seem in the human scale—are as minor eddies in the two vast star streams that are moving in opposite directions through the portion of space in which we find ourselves. These two star streams, comprising not less than half a million members, including most of the brighter stars, have met and mingled like counter-currents in the region of space about us. But their individual members are so far separated that danger of collision is minimized.

The discovery of these gigantic star streams was made about the year 1904 by the Dutch astronomer Professor Kapteyn, of Gröningen, in the course of his laborious microscopic measurements of the location of about a quarter of a million stars on number-

THE GROUP OF THE PLEIADES OR "LITTLE DIPPER"

The small picture shows the stars as viewed through an ordinary telescope; the large picture, the nebulous masses revealed by the Mt. Wilson reflector

less photographic plates. An Englishman, Mr. H. C. Plummer made the same discovery through independent observations almost simultaneously.

These vast star streams are moving in nearly opposite directions in the plane of the Milky Way. But they do not include the stars of the Milky Way itself. The myriad clusters that make up that galaxy lie far out beyond the star streams. So distant are they that they show neither proper motion nor parallax nor actual motion. For the most part they are too faint to be tested accurately with the spectroscope. The actual forms of the streams or clusters into which they appear to be grouped are as yet only matters for conjecture. The distances at which these swarming myriads are aggregated staggers even the astronomical imagination. It is probably not less than three thousand light-years.

If all the stars of the Milky Way had been blotted out of existence at about the time when Moses was leading the Children of Israel out of Egypt, these stars would still seem to shine for us just as they do. And as to certain of the nebulae, the question has recently been revived as to whether they may not in reality constitute isolated universes at distances still more unthinkable—each one a galaxy of stars comparable to our own. But data are lacking for adequate judgment as to this conjecture.

THE SCHEME OF THE UNIVERSE

If, by way of summary, we attempt to interpret the observed phenomena of star clustering and star movement just outlined, it would appear that the

bulk of the stars, exclusive of those of the Milky Way, form a vast lens-shaped structure.

Our solar system is seemingly not far from the center of the lens.

The far distant clusters that make up the Milky Way lie coiled about the edges of the lens.

The stars that make up the nearby streaming clusters just referred to all lie in the central lens. As we turn our telescopes toward the flattened surface of the lens (that is to say, toward the galactic poles) the stars seem to thin out. Our telescopes seem to penetrate to the confines of the universe in these directions. Toward the rims of the lens the thinning out is less obvious, since we now take in the countless myriads of the Milky Way; yet even here there is a relative falling off in numbers as the smallest magnitudes are reached, suggesting that here also we are actually penetrating to the confines of the system,—if you please to the borders of the universe. Clusters of stars, as Mr. S. Waters has shown, are grouped in the region of the Milky Way; whereas nebulae group themselves as far as possible away from it. But the meaning of this arrangement no one at present knows.

As we attempt to picture in imagination this vast lenticular structure comprising in the aggregate all the matter of the universe, the thought comes naturally to mind that the entire system with its hundred million or thousand million stars may be whirling about the axis of the galactic poles, with some giant sun—so distant that it seems to us no different from other stars—at its center of revolution.

The suggestion implies no obvious improbability. The entire visible universe might well enough be one vast spiral nebula, revolving about a central body or about a center of gravity in empty space. But this is sheer conjecture. It will remain for the star-gazers of the ensuing decades, through comparison of photographic star charts taken at long intervals, to find out whether this or something totally different is the general scheme of the universe.

Meantime the astronomers of our own day, with their studies of the groupings and streamings of the nearer stars, have given us clear glimpses into certain secrets of the celestial mechanism that only yesterday belonged not merely to the unknown but seemingly to the unknowable.

III

WEIGHING THE WORLDS

TO speak of the weight of the world is to take obvious liberties with the meaning of words. Weight is the familiar term by which we indicate the attraction exerted by the earth on any given portion of matter at its surface. Since the earth as a whole obviously can not attract itself, it is in a sense a misnomer to speak of it as having weight. A more exact usage of words makes it necessary to speak of the earth's mass rather than its weight. But inasmuch as the only method of determining the mass of any substance with which the average reader is familiar is to determine its weight, the two words have come to seem equivalents in common parlance, and to speak of weighing the world conveys an altogether precise and accurate idea of the feat accomplished in what is more technically decribed as determining the earth's mass.

There are several methods by which this paradoxical feat of weighing the earth may be accomplished. The one which was first put to the test depends upon the principle of determining the attractive influence of the mass of a mountain as balanced against the attraction of the earth as a whole, which latter attraction, it should be explained, is exerted

precisely as if the entire mass of the earth were located at its center. The fact that the gravitational influence of a spherical body is thus exerted was demonstrated by Newton himself. To balance the pull of a mountain against the pull of the earth is not unlike testing the strength of a bar of steel by seeing how much it is bent by a push or pull of known force. A fundamental difficulty with the method, however, is that the exact mass of the mountain itself can never be known with absolute accuracy, although careful surveys may determine the precise bulk of the mountain, and deep borings may give a fairly accurate knowledge of the kind of rock that makes up its structure. Nevertheless a certain measure of success attended this method.

TESTS WITH A PENDULUM

The first important efforts to utilize it were made by a French commission of which M. Bouguer was the most prominent member, which, as long ago as 1740, made an official trip to South America the chief purpose of which was the measuring of a degree of latitude at the equator. The commission supplemented its work, however, by making careful observations of the swing of the pendulum at various high altitudes, and in particular on a plateau of the Andes, as compared with the swing of the pendulum at sea level. It has been understood since the time of Galileo that a pendulum of given length oscillates with unvarying rapidity at the sea level. The rate of oscillation changes, however, if the pendulum is carried to a high altitude, being thus farther removed

from the focus of gravitation at the earth's center. Gravitation, it will be recalled, decreases with the square of the distance, and although the altitudes at which experiments may be conducted are at most only a few miles, as contrasted with the four thousand mile radius of the earth, yet pendulums may be constructed of sufficient delicacy to mark the difference; and of course the theoretical difference between the earth's gravitation pull at sea level and at an altitude of let us say five miles is a matter of simple computation. Where, however, a pendulum test is made on a high plateau, the disturbing influence of the mass of rock making up the plateau is measureable, because this mass tugs at the pendulum and makes it swing a little faster than it theoretically should do. The amount of variation determines the relation between the mass of the plateau and the total mass of the earth itself; and from this proportion the total mass of the earth may be calculated, if the mass of the plateau is known.

Another method of utilizing a localized mass, different only in detail from that just outlined, is to operate with a plumb line on either side of a large hill or mountain of the "hogback" type, noting the extent to which the plumb line is pulled away from the vertical by the attraction of the mountain. Astronomical observations determining the true vertical, and the actual deflection is matter of observation, but it is necessary to survey the mountain accurately and determine as closely as possible the precise character of the rocks of which it is composed. Classical experiments of this type were made

by the British astronomer royal Maskelyne about the year 1774, and results were obtained which gave at least a general notion of the mass of the earth. But, as has been said, all experiments of this type, are lacking in accuracy because it can never be possible to determine with strict reliability the mass of the mountain.

THE CAVENDISH TEST

A test of a far more accurate type was contemplated more than a century ago by the Rev. John Michell, an Englishman, who constructed an apparatus which he did not live to operate but which afterward came into the hands of the famous Cavendish and by him was used to effect what may be considered the first fairly accurate weighing of the earth in the years 1797-98. The apparatus consisted essentially of two lead balls each two inches in diameter placed at the ends of a rod suspended at its center by a long wire. Proper caution being taken to shield the apparatus from draughts of air, it was provided that two other leaden balls, each twelve inches in diameter, might be brought near the small suspended balls, on opposite sides. If, then, the attraction sufficed, the small balls would be drawn toward the larger ones by a movement which could be measured by the swing of the connecting rod. The exact distance between the centers of the large and small balls being measured, and the mass of the balls being accurately determined, the observed deflection, measurable in terms of the torsional stress of the suspending wire, gave the third term of a proportion,

the remaining term of which, according to a well-known formula of the mathematician, would be the mass of the earth.

As the result of a long series of tests made with this apparatus, Cavendish calculated that the average density of our globe is 5.45, the density of water.

Cavendish's experiment was scarcely improved upon for almost one hundred years though many times repeated. Then in 1893 Professor Boys of Oxford repeated his tests, with an apparatus of far greater delicacy than any that had been available. The essential improvement introduced by Professor Boys consisted of using a thread of quartz instead of a wire to suspend the balanced balls. The quartz thread is made by shooting an arrow dipped in molten glass, and it constitutes a gossamer filament of almost unbelievable tenuity far stronger than steel and of marvelous elasticity. It has been alleged that a single gram of sand would furnish material for a thousand miles of this quartz filament. Whatever the truth of this estimate, the quartz thread has unique qualities, and the earth-weighing apparatus which Professor Boys constructed with its aid substituted balls one-quarter of an inch in diameter for the two-inch balls of the original Cavendish instrument; these tiny balls being suspended on a rod only half an inch in length and deflected in the various experiments by sets of balls 4¼ and 2¼ inches in diameter respectively. The apparatus was operated in a partial vacuum, the deflection being noted with a telescope. The adjustment was so delicate that even the tremor caused by distant earthquake was

detected, and the slightest tremor, as from some one walking in the house, put the apparatus quite out of commission.

The final result of Professor Boys' test was to give the figures 5.527 as the average density of the earth in the comparison with water. Still more recently Mariaschein of Bohemia has repeated Professor Boys' experiments and fully confirmed his results, so it seems fairly established that the density of the earth does not differ greatly from the figure given. The weight of our globe, then, is a trifle more than five and one-half times what it would be if it were composed entirely of water. Stated in tons, the weight runs into unmeaning figures; but the aggregate furnishes a useful unit in computing the bulk of the other planetary bodies. When stars are in question, the bulk of the sun furnishes a more convenient unit as we shall see. To estimate the bulk of a star in terms of the earth's mass would be like measuring the weight of an elephant in grams, or computing the life-time of a man in hours.

Reference should be made to earth-weighing tests of another kind made by Airy and others by comparing the pendulum swing at the earth's surface and in the depths of mines; and to Professor Poynting's wonderfully delicate tests with the balance, in which a fifty-pound weight was seemingly given increased weight by bringing a 350-pound mass directly beneath the scale. Professor Poynting's experiments were of such delicacy as to be equivalent, he tells us, to balancing the entire British population of 40,000,000 individuals against an equivalent weight, and

then noting the difference of weight due to the inclusion or exclusion of one small boy. Indeed, it is further stated that the test would determine whether or not the boy wore boots! It is interesting to observe that the results obtained by Professor Poynting are in close agreement with those secured by the Cavendish method. He makes the average mass of the earth 5.493; as against the 5.527 of Professor Boys. The most recent investigations, then, show the sagacity of Newton's original guess, that the mass of the earth would be found to be between five and six times that of a similar globe of water.

WEIGHING THE MOON

In finding the mass of the moon or of any other sidereal body, the great law of universal gravitation is invoked as in weighing the earth. We have, indeed, no other means of making such a test, and before Newton's exposition of the law of gravitation no one could have had more than the vaguest notion of the mass of any planetary or stellar body. Granted a knowledge of the law of gravitation, together with a recognition of the principle of inertia, it becomes possible to calculate the mass of many of the astronomical bodies with comparative ease; provided the size of the orbit in which the bodies move can be determined.

The law of gravitation expresses the fact that the attraction between any two masses of matter varies inversely as the square of their mutual distance and directly as the product of their masses. The law of inertia states the fundamental principle that any

mass of matter if at rest will remain forever at rest unless operated upon by some disturbing force, and that a mass in motion tends if undisturbed to move on in a straight line at an unvarying rate of speed forever. Applied to any body that is revolving in an orbit, the result is this: at any given moment the body tends to take a tangential course which would carry it off in a right line farther and farther from its primary; but the attraction of gravitation pulls it away from the tangential course, so that in effect it falls toward the primary. If the two tendencies just balance, the body neither flies off into space nor falls actually nearer its primary, but maintains an orbital course at a uniform distance. Such is, in point of fact, the condition of the earth itself in revolving about the sun, and of the moon in its course about the earth.

It is clear that the rate of revolution of a small body at a given distance from its primary is largely dependent upon the mass of the primary itself. If, for example, the mass of the sun were to be materially changed, the entire solar system would at once be thrown out of equilibrium, and all the planets would of necessity seek new orbits before that equilibrium could be restored.

But it must be borne in mind that a planetary body does not in a strict interpretation revolve about its primary; the fact being that primary and satellite revolve about a common center. Where the primary is enormously larger than the satellite, however, as in the case of our sun and his planetary family, the motion of the larger body may practically be ignored

in all but the most delicate calculations. The centre of revolution connecting the sun and the earth, for example, lies almost immeasurably near the centre of the sun. The balance is like that of a large man swinging a tiny marble round and round at the end of a string. The same thing is true of the relations between most of the planets and their satellites. As a rule the largest satellites have less than one-thousandth the mass of their primaries. The only exception in the solar system, is found in the case of the earth itself, our moon being vastly larger, proportionately, than the satellite of any other planet.

As it happens, the relatively large size of our moon greatly facilitates the task of the astronomer in weighing that body. The moon is, in point of fact, of so significant a size that the centre of its orbit of revolution is considerably removed from the centre of the earth, although still within the circumference of the earth itself. This centre of mutual revolution lies, in point of fact, about 2880 miles from the centre of the earth, or, stated otherwise, not much over 1100 miles beneath the earth's surface. About this centre the earth revolves in a monthly orbit just as does the moon, and it is this fact that supplies the astronomer with the easiest method of computing the weight of our satellite.

If we consider for a moment the mutual relations of the earth and the moon, it will be obvious that the earth, in describing its monthly revolution, in effect wabbles back and forth, like a wheel rotating about a point intermediate between its hub and its periphery. If it could be viewed from a stationary point

out in space, it would seem to shift its position back and forth, always however maintaining the same relation to the moon. And, contrawise, a stationary object in space as viewed from the earth would seem to shift its position back and forth in half-monthly periods. The amount of this shift would be so small in the case of bodies at stellar distances as to be quite inappreciable; but on the other hand it would affect the seeming position of a body as near as the sun quite materially.

In point of fact, such an oscillation in the seeming position of the sun is observed actually to occur. As the earth rotates twenty-eight times on its axis during each monthly period of revolution, the sun is brought as many times to the meridian during each such period; and it is observed that when the moon is "new" and again when it is "full"—at which times, it will be obvious, the orbital centre of earth and moon falls in direct line with the sun and the moon—the sun comes to meridian exactly at the predicted time. But when the moon is in the first quarter—the line connecting the earth and moon being at right angles to the earth and the sun—the sun's seeming position will be shifted in such wise that it comes to the meridian a little later than the predicted time; and again when the moon is in the last quarter a seeming shift in the opposite direction brings the sun to the meridian a little before the predicted time. Of course at intermediate periods there is a transitional shift in one direction or the other day by day.

The measurement of the maximum shift in the sun's seeming position determines the actual shift in

the earth's position due to its orbital oscillation about the moon. As already stated the amount of this shift is found to be about 2880 miles. This distance, as computation shows, is about one-eightieth of the moon's distance from the earth. It follows that the mass of the moon is one-eightieth the mass of the earth.

There are several other methods by which the mass of our satellite is computed. And the results of these other tests are in substantial accordance with this one. There is little doubt, then, that the weight of the moon is thus determined with a considerable degree of accuracy. It is notable, however, that the mass as thus determined is much smaller than would be expected from the moon's size. In point of fact the earth's satellite seems to be composed of a much lighter material than the substance of the earth itself. This seems rather curious, but is not absolutely inconsistent with the older or newer theories of cosmogony.

WEIGHING THE SUN

To find the mass of the sun is a curiously simple problem in arithmetic, provided we take for granted a knowledge of the diameter of the earth's orbit and at the same time disregard the ellipticity of the orbit. Assuming, then, that the earth's distance from the sun is 92,900,000 miles, and that the orbit is approximately circular, a simple computation will show that the earth must traverse the distance of about eighteen and a half miles per second in order to complete its journey about the sun in its observed natural

period. Another computation will show that in the circle thus constituting the earth's path, an arc eighteen and a half miles in length departs from a straight line only an infinitesimal amount; in short, by just about one-ninth of an inch. In other words, the earth in compassing a distance of eighteen and a half miles falls toward the sun, under the influence of gravitation, by one-ninth of an inch.

Now it is familiar knowledge that an object near the earth's surface falls toward the earth's centre sixteen feet in the first second. It follows that the force of gravitation as exerted by the earth on objects at its circumference is greater than the force of gravitation exerted by the sun on matter at the earth's distance in the ratio of sixteen feet to one-ninth of an inch. But objects at the earth's centre are only 3964 miles from the earth's centre of gravity, whereas the earth is 92,900,000 miles from the sun's centre of gravity; and as the force of gravitation decreases with the square of the distance, the ratio that expresses the relation between the actual gravitation of the earth and that of the sun is the ratio between the square of 3964 miles and the square of 92,900,000 miles.

The arithmetical computation being made it appears that the actual mass of the sun is 332,000 times that of the earth. In other words, could the sun be placed on one scale of a gigantic balance, 332,000 globes such as ours must be placed in the other scale to offset his weight. Even as colossal a weight as this, however, does not come up to the expectations based simply on the sun's bulk; for it appears that

the structure of the sun is far less dense than that of the earth, his substance having indeed only about one and one-half times the density of water. This, however, is quite what might be expected considering the revelations of the spectroscope as to the gaseous nature of such portions of the sun's surface as can be explored. It is held, indeed, that the entire substance of the sun may be regarded as gaseous, although, owing to enormous gravitational compression, the main bulk of the sun's interior structure doubtless has a consistency comparable rather to that of a very dense liquid than to what we ordinarily term a gas.

But while the weighing of the sun seems thus to be a very simple matter, it will be recalled that we assumed at the outset a knowledge of the actual distance that separates the earth from its primary, and that this distance has an altogether vital share in the calculation. But how is the sun's distance itself to be determined?

The question is a very vital one, not only in the matter of estimating the sun's mass but in an endless number of computations with reference to the distance and the bulk of the various members of the solar system. The distance of the earth from the sun is, indeed, a convenient yard-stick with which to measure planetary distances. It is quite possible to construct a plan showing the relative distances of all the different planets from the sun, and to chart with accuracy their orbits, without having any definite knowledge as to the actual distances involved in any part of the chart. We could state with entire

precision that the diameter of the orbit of Jupiter is so many times the radius of the earth's orbit even though we were quite unable to translate either figure into terms of precise miles.

Similarly we could estimate the relative bulk of the various planets and the relative sizes of the orbits of their various satellites, even though nothing were known as to the exact distances in question. But in order that our chart of the solar system should take on the satisfying quality of a map drawn to a known scale, and in order that we should translate terms of relative bulk into terms of actual bulk, it is essential to know the actual distance between one pair or another of our charted bodies. One such distance known, other distances may be computed. But how are we to measure, in terms of miles or any other precise unit, any one of the planetary distances?

The most natural method that suggests itself would be to take the "parallax" of the sun by applying the old familiar principle of triangulation—the same principle by which the seaman determines the distance of a ship and the surveyor charts the topography of a region—to the measurement of the sun's distance. Theoretically nothing more would be necessary than to take the direction of the sun from two stations at opposite points of the earth's surface, using the earth's diameter therefore as a base line, and noting the angular distance between the two lines of observation. In default of stations precisely as located, any two points fairly distant would seemingly answer, just as the surveyor may use a variable base line, a computation sufficing to make the necessary

corrections that will give the size of the angle subtended by the earth's radius as viewed from the sun, which is the parallax desired. Such is, in point of fact, the method by which the distance of the moon is determined. But in attempting to apply the method to measurement of the parallax of the sun, complications arise that have proved quite insuperable. The direct observation of the sun presents obvious difficulties because of the intense brilliancy and heat of its surface, and it is found almost impossible to focus on its precise centre with needful accuracy. The actual angle to be measured is now known (thanks to other methods) to be not far from 8.8 seconds of arc; and this, as Professor F. R. Moulton points out, makes the apparent shift in the sun's position as viewed from opposite sides of the earth closely equivalent to the shift of an object a mile distant as viewed first with one eye and then with the other. The angle is too small to be measured under the given conditions. So it is necessary to find another way of estimating the sun's parallax.

It was suggested by the celebrated Halley, discoverer of the comet that bears his name, that a means of measuring the sun's parallax might be afforded by observation of a transit of Venus; that is to say of the passage of Venus across the sun's face on one of those rare occasions when the course of our sister planet carries her directly between the earth and the sun. Owing to the slightly varying planes of the planetary orbits, a transit of Venus is a relatively infrequent occurrence. When a transit does occur, however, it is repeated after an interval

of only eight years. Thus transits occurred in the years 1761 and 1769; but the next transit did not occur until 1874, followed by the transit of 1882.

It was thought by Halley, and following him by astronomers in general, that by noting the precise instant when the planet touched the limb of the sun, as viewed from different observation stations, it would be possible, owing to the difference of time at which this so-called occultation would occur as viewed at different longitudes, to compute accurately the distance of Venus from the earth, and, secondarily, to obtain the desired parallax of the sun. But although important expeditions were planned, whereby astronomers took up their location with proper instruments at various points of the earth from which the transit of Venus would be visible, the final results of all series of observations were very disappointing. To say nothing of uncertainties of observation due to clouds, which are likely to obscure the sun at precisely the wrong moment, there are inherent difficulties due to the refractive effects of the atmosphere of Venus; so even after the transit of 1882 there still remained elements of doubt as to the sun's precise parallax, and therefore, of course as to his exact distance.

AID FROM MARS AND EROS

Another method of attempting to solve the problem would be to take the parallax of our neighbor Mars at one of those periods when he chances to be relatively near us. This attempt has been made again and again, and with a certain measure of success;

but unfortunately Mars, even at his nearest, is something like 50,000,000 miles distant, and his relatively large size adds to the difficulty of focusing on his centre with the degree of accuracy necessary for this delicate measurement. Nevertheless the estimates of the sun's parallax deduced from measurement of the parallax of Mars are closely in accord with other estimates and serve to confirm our knowledge of the true scale of the planetary map.

In point of fact the various estimates were so concordant that the actual parallax of the sun was known toward the close of the nineteenth century with a degree of accuracy that would fairly satisfy any one but an astronomer. Professor Moulton tells us that in 1891 Harkness made a discussion of all the material bearing on the subject and obtained as a final value of the solar parallax 8.809 seconds with a possible variation of .006 of a second; and that in 1896 Newton obtained from all available material the number 8.797 seconds, with a possible plus or minus variation of .007 of a second. To the layman this may seem accurate enough; but the astronomer is always eager to grasp new means of verifying his measurements and calculations, and so there was intense interest manifested in the discovery, made in 1898, of the little planetoid called Eros.

The reason was this: Planetoids in general, it will be recalled, having orbits lying between Mars and Jupiter. But it was soon noted that the orbit of Eros is extremely eccentric, and the computation showed that one part of its journey would bring it within the orbit of Mars, and hence nearer to us than

any other known member of the sun's planetary family. Moreover it fortunately chanced that Eros was at the time of its discovery approaching the portion of its orbit which would bring it nearer the earth. Sir David Gill, at the Cape Town Observatory, had made very accurate determinations of the sun's distance by testing the planetoids Victoria, Isis, and Sappho, notwithstanding their distance. It seemed obvious that Eros would afford still better opportunity for making the all-important measurement.

The expectations were fully realized. In the winter of 1900-1901, Eros was at the nearest point, and elaborate series of observations were made, chiefly by the photographic method, at many different observatories, with an eye to the detection of the solar parallax. The computations from these observations are matters of complex mathematics, but the preliminary discussions gave results closely in accord with the previous estimates of the sun's parallax.

THE SPECTROSCOPIC METHOD

The newest method of measuring the sun's distance is what seems to the layman the rather curious one of aiming a telescope at a distant star and recording the positions of the spectroscopic lines by photography, and then aiming again at the same star six months later and again recording the positions of the lines.

The explanation of this seeming puzzle is that the lines in the spectrum (as we have elsewhere noted)

are shifted in one direction if you are approaching the light-giving object, and in the other direction if you are receding from it. With the great resolving power of the modern spectrograph used in connection with a big telescope, it is possible thus to measure accurately the shift of lines and deduce the speed of the moving body. For the purposes of this measurement it does not matter whether the light-producing object is moving toward you, or whether you are moving toward the light-producing body.

In the case under consideration, the astronomer measures the motion of the earth plus the motion of the star. But the earth is traveling in opposite directions at the two periods when the photographs are taken, whereas presumably the flight of the star is unvarying. So the difference between the velocities recorded in the two measurements will represent twice the actual speed of the earth in its flight about the sun. This speed being thus accurately measured, it is a very simple problem in arithmetic to determine the distance which the earth traverses in a year; which is obviously equivalent to determining the size of the earth's orbit and hence the average distance of the sun.

In the number of the Publications of the Astronomical Society of the Pacific for October, 1912, Professor Arthur B. Turner of the College of the City of New York, tells of recent estimates of the sun's distance made by this method. But he points out that the problem is by no means as simple as it seems at first sight, because of certain practical complications that cannot be avoided.

"In the first place," says Professor Turner, "stars of a suitable spectral type and magnitude for velocity determinations are not found exactly in the ecliptic; second, the Earth's orbit is slightly elliptical; which makes the Earth's velocity a variable quantity; third, it also rotates on an axis and the observer has a component of velocity relative to the star depending upon the hour angle of the observation; fourth, the earth and moon revolve about a common center of gravity, and planetary perturbations also change slightly the elliptic velocity of the earth; fifth, some of the larger planets, like *Jupiter* and *Saturn,* swing the sun out of position sufficiently to affect the star's motion with respect to the sun's center; sixth, the star may be a spectroscopic binary and have a variable velocity with respect to the observer (the component of the sun's motion through space in the direction of a star is assumed to be constant); and, seventh, the observations cannot be taken exactly at quadrature with the sun for a number of plates or spectrograms must be taken of each star at successive quadratures."

That would seem to make the problem almost hopelessly complex. But Professor Turner hastens to assure us that allowance can be made for all these departures from ideal conditions, and that when such allowance has been made, with the resources of the modern mathematician, the resulting value of the sun's distance has a very high degree of accuracy. Reviewing a piece of work started by Sir David Gill at the Royal Observatory, Cape of Good Hope, and completed under Director S. S. Hough, in which the

estimates were based on 302 spectrograms made between February 1906 and May 1908, Professor Turner tells us that the final most probable value of the solar parallax (which is the astronomical way of stating the case) was 8.800 seconds of arc, with a possible variation of 0.006 seconds. This agrees remarkably well with the value of the reports made in February 1912, by Professor A. R. Hinks from a later discussion of some hundreds of plates of the planetoid Eros taken at twelve observatories during the so-called opposition of that body in 1900-1901; this value being 8.807 seconds, with a possible variation of 0.0027.

Being interpreted in terms more comprehensible to the average mind, this means that the earth's mean distance from the sun is known within about 30,000 miles,—a figure which seems infinitesimal in comparison with the actual distance of almost ninety-three million miles; the variation being equivalent to only twenty inches in a mile. The best determinations made from Mars had left a possible variation of a million miles; and Professor Gill's most accurate measurement of the minor planets available before the discovery of Eros still allowed an uncertainty of 100,000 miles.

But even the new figure does not satisfy the astronomers; and Professor Turner tells us that a programme now under way at the Cape Observatory has to do with the observation of 365 stars and that when completed the radial value of at least fifty stars, observed near quadrature of the sun, suitable for the determination of the solar parallax, will give us "in

a few more years" the spectroscope determination of the sun's distance with a degree of accuracy equal to that of any other method.

Meantime the various types of measurement are so closely in harmony that we may look with much confidence on the figure 92,897,000 miles as representing the earth's average distance from the sun. This, then, is the unit distance which serves as a yard stick in measuring the planetary distances. With its aid we compute the mass of the sun, and also, as will appear in a moment, the masses of all but two of the fraternity of major planets.

WEIGHING THE PLANETS

In determining the mass of a planet, no new principle is involved. All that is necessary is to note carefully the distance from the planet of one of its satellites, and the precise period of revolution of that satellite. As we have seen, the rate of revolution at any given distance is determined by the combined masses of the planet and satellite. So what will really be determined when the other data are known is the joint mass of planet and satellite. But with the single exception of the moon, the satellites are so small in comparison with the bulk of their primaries that their weight may virtually be disregarded, and for the purposes of rough calculation it may be assumed that the entire mass of the system is located in the planet itself.

Speaking in astronomical terms, the planets are relatively near the earth, and it is possible, with the modern instruments, to measure the orbits of their

satellites with a good degree of accuracy. Such measurement, stated in terms of angular distance, would obviously have no definite meaning unless the actual distance of the planet were known. But we have already seen that these distances are matters of precise knowledge, so the observations of the atronomer as to the orbits of the various satellites of the different planets can be translated into terms of miles and thus supply the basis for simple computations through which the masses of the planets are made known; otherwise stated, through which the planets are weighed.

Mathematicians have discovered that the computation in question may be very conveniently performed if the problem is stated in the form of a proportion in which the masses and the orbits of the satellites of two different planetary systems are utilized. For this purpose, the known mass and the orbital time and distance of the earth and moon will naturally form the standard of comparison. The formula implied was stated as follows by the late Charles A. Young, the famous Princeton astronomer: "The united mass of a body and its satellite is to the united mass of a second body and its satellite, as the cube of the distance of the first satellite [from its primary] divided by the square of its period is to the cube of the distance of the second satellite [from its primary] divided by the square of its period."

This formula obviously enables the astronomer to compare, by the simplest mathematical computation, the masses of any two bodies which have attendants revolving round them. Thus the mass of any planet

having a satellite of measured distance and revolution period may be computed without difficulty. It must not be supposed, however, that it is an altogether simple matter to make accurate determination of the orbital distance and period of revolution of a satellite in the case of the more distant planets. It will be recalled that both Uranus and Neptune are invisible to the naked eye. The satellite of Neptune is barely visible under the resolving powers of the largest telescopes; and the same thing is true of the smaller satellites of even such relatively near planets as Jupiter and Saturn. Yet the smallest satellites, particularly if they are relatively far removed from their primaries, are precisely the ones best adapted for accurate observation of their orbital distances. Hence the accurate weighing of the planets has been greatly facilitated by the use of the large modern telescopes; and, indeed, was in the case of the outer planets quite impossible of performance until the great instruments of the Yerkes and Lick and Mt. Wilson Observatories were installed.

Now, however, it is certain that the masses of Mars, of Jupiter, of Saturn, of Uranus, and of Neptune have been determined with a fair degree of accuracy. As the diameters of these planets can of course be measured by direct observation (their exact distance at the particular time of observation being determined) their actual size and hence the average density of their structures may be computed; average density being, of course, expressed in the ratio between the bulk and the mass of any given structure.

The results of these measurements and computations show that the great outlying planets are of very low density, no one of them being as dense as the sun. The density of water being taken as unity, the density of Jupiter is found to be 1.33, that of Saturn 0.72, that of Uranus 1.22, and that of Neptune 1.11. When it is recalled that the density of the earth is about 5.50, it will be seen that the outlying planets are very tenuous structures. Like the sun, they are doubtless gaseous in constitution, although their great bulk gives them a gravitational power that condenses their average substance to a fluid consistency, Jupiter, as the figures just cited show, being about one-third denser than water, and Saturn, the most tenuous of all, less than three-quarters as dense.

Notwithstanding their tenuous structure, however, the outlying planets are of such enormous bulk that their total mass quite dwarfs that of the earth. Jupiter would require more than 317 globes like ours to balance its weight, and Saturn would more than tip the beam against 94 earths. Uranus and Neptune, however, are less colossal, the weight of the former being only 14.6, and that of the latter only 17 times that of our globe.

Our nearer neighbor Mars, on the other hand, has a structure more like that of our own planet, its average density being 3.95, or about seven-tenths that of the earth. Its total mass is a little less than one-ninth (0.11) that of the earth.

The two remaining major planets, Mercury and Venus, are without satellites, and hence can not be

weighed in the facile manner just indicated. In attempting to compute their mass, it is necessary to take into account their observed perturbing effects on the orbits of comets that chance to pass near them from time to time, and at best the results obtained are somewhat less trustworthy than those secured in the case of the other planets. Large numbers of observations, however, have given fairly concurrent results, and it is computed that Venus weighs about $\frac{8}{10}$ and little Mercury about $\frac{1}{33}$ as much as the earth. The density of Venus is 4.89 and that of Mercury 3.70. These inferior planets are, therefore, not very dissimilar to the earth in point of solidarity.

ARE THE PLANETS INHABITED?

Time out of mind the question whether there are human inhabitants on the planets has been matter of interest and controversy. The question has been argued pro and con from many standpoints, including the theological, but it can not fairly be said to be settled even in our own day. In a recent book Professor E. Walter Maunder, Superintendent of the Solar Department of the Royal Observatory at Greenwich, England, discussed the question of the habitability of the various planets, and gave what may be considered a fair presentation of the attitude of the generality of astronomers toward this interesting subject.

As to all but two of the planets, the question may be answered negatively with entire assurance. The great outlying planets Jupiter, Saturn, Uranus, and

Neptune, were pretty generally supposed to be not unlikely abodes for human beings by astronomers even of half a century ago. But we have just seen that the recent tests prove that those great bodies have far too tenuous a structure to be other than gaseous in constitution; at the very most their central portions may have the structure of molten liquids. Jupiter's equatorial portions are observed to rotate more rapidly than parts nearer the poles, thus proving by direct observation the condition of fluidity argued by the mathematicians. In a word, then, these gigantic planets are worlds in the making. By no possibility can they at present give habitation to living creatures in any wise comparable to those that inhabit the earth.

For a quite different reason the tiny interior planet Mercury is uninhabitable. It is all but certain that this planet has been brought by tidal strain to a condition comparable to that of our moon in which its period of rotation corresponds exactly to its period of revolution, so that it turns one face always to the sun just as the moon always turns one face to the earth. The result must be that one half the surface of Mercury is intolerably hot and the other half intolerably cold as well as perpetually dark.

Overlooking the company of tiny asteroids, there remain two planets, Mars and Venus. These are nearest neighbors, and they rather closely resemble the earth in size and density of structure. They are both of such constitution as to give the idea of their habitability greater or less plausibility; and that Mars is in reality inhabited has become almost a

matter of tacit belief. It has become customary to speak of our neighbors the Martians quite as if they had assured existence. Every one has heard, too, of the canals of Mars, and most readers are probably familiar with the claim made by Professor Percival Lowell that these canals can not possibly be of natural origin but must represent the work of intelligent beings. Professor Lowell cites in proof of the artificiality of these canals, their straightness, their uniform size, and their extreme tenuity; also the dual character of some of them, and their relation to certain spots which he interprets as oases; and in general a systematic net-working by both canals and spots of the whole surface of the planet. He believes that these markings represent the vegetation about actual canals that convey water (supplied by a melting ice-cap) from the polar regions and irrigate the arid surface of the planet.

Not merely the interpretation of these lines but their existence has been challenged by various observers. The fine drawings of Mars made by Keeler and Barnard with the 36-inch Lick telescope show certain curious shadings and lines, but nothing closely corresponding to Professor Lowell's pictures. Nor does the photographic plate reveal anything more than vaguely suggesting an intricate system of canals. But it is conceded that these canals, if they exist, lie almost at the limits of vision, and it is probable that the question of their existence will long remain a matter of controversy. Professor Maunder, however, believes that he has settled the question definitely, and it must be admitted that he

presents very striking evidence against Professor Lowell's theory.

Professor Maunder's experiments were made, curiously enough, not with the aid of telescopes, but in an ordinary school-room, the observers being a company of schoolboys. He placed on the wall a diagram on which he had made a few spots or irregular markings. Boys at different points in the schoolroom were asked to look carefully at this diagram and to draw what they saw. The results were striking. The boys nearest the diagram detected the little irregular markings and represented them under their true forms. Those at the back of the room saw only the broadest features of the diagram, and made vague drawings that might represent continents and seas. But the boys in the middle of the room, unable to recognize the markings as they really existed, gained an illusive impression of a network of straight lines, sometimes with dots at the points of meeting.

"Advancing from a distance toward the diagram," says Professor Maunder, "the process of development became quite clear. At the back of the room no straight lines were seen; as the observer came slowly forward, first one straight line would appear completely, then another, and so on till all the chief canals drawn by Schiaparelli and Lowell in the region represented had come into evidence in their proper places. Advancing still farther, the canals disappeared, and the little irregular markings which had given rise to them were perceived in their true forms."

This experiment suggests, then, that the discovery

of "canals" net-working the surface of Mars depends upon the acuteness of vision of the observer, or upon the size of the telescope that aids his vision. The Italian astronomer Schiaparelli, who first observed the canals, was gifted with peculiarly acute vision; and Profesor Lowell's observations are made in an atmosphere of great clearness. These observers, and a few others who have thought they saw the markings, would be likened by Professor Maunder to the children in the middle of his schoolroom. The other observers, who failed to see the markings, are like the children at the back of the room or at the front, according to the more or less favorable conditions under which their observations are made.

It seems more than probable, then, that the canals of Mars are an optical illusion, and that their presence can not be legitimately invoked as proving the habitation of our neighbor planet by intelligent beings. Meantime students of solar physics calculate rather conclusively that unless Mars is blanketed with a rather dense atmosphere—and the reverse of this is believed to be the case—its surface condition must be one of very low temperature, making it altogether unlikely that any animal life comparable to that of the earth can exist on the planet.

As to Venus, the conditions are very different, and in Professor Maunder's view the probability that this planet may be the abode of life is considerably greater. Venus has a dense atmosphere and it is near enough to the sun to receive nearly double the heat and light received by the earth. So there is no obvious intrinsic reason why life may not exist

on Venus, provided that planet rotates in a manner to expose first one side and then another to the sun's influence. But it chances that this is a matter of doubt. It was formerly supposed that the period of rotation of Venus had been accurately determined, particularly by the Italian astronomer De Vico, who made the period 23 hours and 21 minutes. But more recently another Italian astronomer, Schiaparelli, whose observations of Mars have just been cited, fixed attention on certain bright spots near the southern horn of Venus (this planet showing phases like those of the moon), and watched them for many consecutive hours. He claimed that the line separating day and night on Venus does not shift to any appreciable extent, hence that Venus really rotates, after the manner of Mercury and the moon, in such a way as to present the same face always to its primary.

Other astronomers have confirmed this observation. If it represents the facts, there can be no question of the uninhabitability of Venus; to quote Professor Maunder, "the side exposed to the sun will wither in a temperature of about 227 degrees Centigrade, in which all moisture will be evaporated; the side remote from it will be bound in eternal ice. In neither hemisphere will water exist in the liquid state; in neither hemisphere will life be possible."

It must be added, however, that recent studies made with the spectroscope have tended to confirm the earlier belief that Venus rotates much as the earth does in a period of approximately twenty-four hours. But the cloudy state of the atmosphere of Venus

makes it difficult to confirm these observations, and the question of the rotation period of the planet is still an open one. On the solution of that question will depend the answer to the other question as to whether Venus may or may not be the abode of life.

WEIGHING THE STARS

It is a natural assumption, speaking from a terrestrial standpoint, that some or many of the stars may have planetary systems comparable to that of our particular star, the sun. Much of this was tacitly assumed in what was said in an earlier chapter about the possible development of stellar systems out of spiral nebulae. But it should be explained that the existence of such minute planetary attendants as those that make up the sun's family is a matter of pure conjecture, subject neither to verification nor refutation unless some far more powerful means of investigation than those provided even by our largest telescopes shall be developed.

To understand this it is only necessary to recall that computation shows that if the nearest star, Alpha Centauri, had a planetary attendant similar to the earth, its astronomers, even if provided with telescopes equal to the great Mt. Wilson reflector, would be unable to discover that our sun has any attendants. The sun itself would appear as a smallish first magnitude star, and the very best that could be hoped would be that the giant Jupiter would be recorded on a photographic plate as a star of less than the twenty-first magnitude at a seeming distance of only five seconds from the sun. Yet Alpha Cen-

tauri, as we have seen, is a very neighborly star, the second nearest star being more than twice as distant. So it is quite beyond the range of present comprehension that any means should ever be developed through which astronomers here on the earth could demonstrate the presence of bodies comparable in size to the earth and its sister planets in connection with the stellar systems.

But while it thus remains an open question as to whether there are small planets revolving about any star other than our sun, it is not at all in doubt that there are vast numbers of stars that are grouped into systems of a different order, comprising two or more stellar bodies of somewhat similar size and therefore making up systems which are to be likened to the relations of the earth and the moon rather than of the sun and planets. These systems have already been referred to as double stars.

The discovery that such double stars exist was made by Sir William Hershel more than a century ago. From that day to this the discovery of double stars has gone on, and, as we have seen, it is now known that this condition appears to be the rule rather than the exception in the sidereal universe. In some cases two stars more or less equal in brilliancy are observed to be revolving in a mutual orbit in such manner as to leave it scarcely open to doubt that the laws of inertia and of gravitation determine their orbits precisely as the same laws determine the orbits of planets about the sun and of satellites about the planets in our solar system. There are other cases in which the backward and

forward shift of a star having no visible companion suggests revolution in connection with a dark companion; and the classical case will be recalled of Sirius, the observed perturbations of which were thus explained some years in advance of the discovery of a companion too dim to be visible until a telescope of unexampled power had been constructed by Alvan Clark.

It is obvious from what we have seen as to the means of weighing planets, that observation of the swing of the two stars in a mutual orbit would enable the astronomer to compute the aggregate mass of the two bodies, if the actual size of their orbit can be determined. To make this determination, however, it is necessary to know the distance of the stars from the point of observation, that is to say from the earth; and this as we have seen is only possible in case the stars are so relatively near that their parallax can be determined by observations taken at opposite points of the earth's orbit. Fortunately it happens, however, that several stars of known parallax are binary stars. Alpha Centauri, the nearest of all, is a binary; and the fact that Sirius, known to everyone as the brilliant Dog Star, is a binary has just been referred to. In both these cases, as well as in several others, the astronomers have been able to translate the observed orbital shift of the stars into terms of actual size of orbit, and thus to compute the joint mass of the duplex system in accordance with the same formula which gives the mass of a planet and its satellite.

It appears that Sirius and his companion have

jointly more than three times (3.7) the mass of the sun. The double star known as 85 Pegasi has a mass more than eleven times that of the sun; and the average mass of the first six pairs of the double stars to be weighed is 3.5 times that of the sun. Meantime the average radiating power is nearly six times that of the sun. So far as these limited observations go, they give warrant to the belief that the sun is a relatively dull star.

In some cases it is possible, with the aid of the modern instruments, to determine the orbits of a pair of double stars so accurately that the relative displacement and therefore the relative sizes of the two may be computed. In the case of Sirius, for example, it appears that the larger member of the pair is 2.5 and the smaller member 1.2 times the size of the sun. It is notable that, although the two bodies are thus not so very different in size, the larger one is nearly 10,000 times as bright as its companion. So great a discrepancy in the brilliancy, in the case of bodies of comparable size, is not easily accounted for. But an even greater difficulty arises when we attempt to explain the case of 85 Pegasi, in which it is computed that one member of the pair is 4.3 times and the other 7.8 times the size of the sun, and in which the smaller member is 100 times as luminous as the larger. Professor Moulton points out that, according to the usual estimates made from spectroscopic appearances, this pair of stars should be much older than the Sirius couple, and that analogy would lead us to expect the smaller mass to be approaching the dark stage, instead of being exceed-

ingly brilliant as it is. But he adds that the data as to the orbits of this pair of stars are still rather uncertain, and that future observations may give corrections that will prove our present estimate of the relative masses to be incorrect.

In explanation of this element of uncertainty, it should be noted that the periods of orbital revolution of the visual binary systems that have been measured, vary from 24 to 196 years, and that the amount of apparent shift in their positions is so excessively minute, even when amplified by our most powerful telescopes, that it is matter for wonder not that there should be uncertainties in the estimate, but that it should be possible to make estimates having any degree of sureness.

SPECTROSCOPIC BINARIES

The feat of weighing visual binaries, however, does not carry us quite to the limits of the astronomers' present-day miracles of world-weighing. The final stage is reached in the case of the so-called spectroscopic binaries. These are pairs of stars so closely linked that even the most powerful telescope reveals the couplet only as a single point of light; yet which are proved by a double shift of their spectroscopic lines—these lines alternately showing single and double—to constitute two foci of radiation,—that is to say two stars. The first discovery of a spectroscopic binary was made at Harvard Observatory by Miss Maury in 1889, through observations of photographs of the well-known bright star Mizar. On examining a series of plates, it was seen

that the spectroscopic lines were doubled periodically, every 52 days, and the only justifiable inference from this is that the star is a binary. Mizar was previously known as a telescopic double, but the second component of the spectroscopic binary is not the one that can be seen with the telescope. In other words, one of the visible components of the spectroscopic binary is itself a double star, the parts of which are too close together to be separated even with the most powerful instrument.

There is yet another type of spectroscopic binary, in which one component is a dark star, and in which the orbital shift of the bright companion is revealed by a backward and forward movement of the spectroscopic lines. To detect this shift it is necessary to use what is called a slit spectroscope at the eyepiece of the telescope and a comparison spectrum. The first binary of this type was discovered by Vogel at Potsdam, also in 1889, the star first observed being the famous variable Algol. Vogel found that the lines of this star shift back and forth in a period precisely conforming to the period of its variability (two days, 20 hours, 49 minutes).

It had long been supposed that the observed variability of Algol must be due to the periodical partial eclipse of the bright star by a dark companion which chanced to be revolving in an orbit precisely in our line of sight. But this remained a pure conjecture until the spectroscopic test proved that the star is a binary revolving in an orbit with a dark companion. Moreover, the shift of the spectroscopic lines agreed perfectly in point of time with the re-

quirements of the explanation, thus making it virtually certain that the explanation is correct.

In recent years large numbers of spectroscopic binaries have been observed, the periods of which vary from 1.45 days to a term of years. The shift of the spectroscopic lines determines the speed of the star, and this makes it possible to compute the actual orbit, provided the star is one of measured parallax. Such is the case, for example, with Miss Maury's first spectroscopic binary Mizar. Vogel's later test showed that the period of this star is about twenty and one-half days. Taken in connection with the size of the orbit this shows that the mass of the pair is about twenty times that of the sun. Here, then, is a case in which the presence of an absolutely invisible body enables the astronomer to determine the aggregate mass of that body and its bright companion. It is not possible, however, by any means at present known to determine with precision the relative mass of the two components. But it is a sufficiently wonderful achievement to demonstrate the existence of a dark star and to gain even an approximate knowledge of its weight.

Indeed, it is hard to conceive of any unexplored field of astronomical discovery that can have a greater wonder than this in store for us.

SOME INTERESTING STAR-GROUPS

The dark stars have peculiar interest because of what they reveal as to star groupings that have greater or less resemblance to the mechanism of the solar system.

A notable example of a star accompanied by dark companions is the pole star itself. Professor Campbell has shown that this star has two dark associates circling about it. One of these is so near that it makes the circuit in about four days; the other so distant that its period of revolution is several years.

There are numerous double stars that may readily be located by the amateur. One of the most interesting is Mizar, already referred to. It is readily located, as it is the second star from the end of the handle of the big dipper. A sharp eye may see that this star has a small companion. A three-inch telescope will show that one of these two stars is white and the other emerald in color. The two are in reality so far apart that to an observer on the small one the large one would look only as a bright star looks from the earth. Yet the spectroscope shows that this larger companion is itself composed of two suns, separated by a distance of about 36,000,000 miles,—something more than the distance of our planet Mercury from the sun. They are more than 100 light years from our system, and no telescope separates the two components. Yet the shift of their spectroscopic lines enables astronomers to compute that Mizar has twenty times the bulk of our sun, and is coming toward us at the rate of twenty miles an hour.

Another interesting double is the small star lying rather inconspicuously in one of the middle arms of the big W-shaped cluster in the constellation Cassiopeia. A small telescope separates the two components, which in reality lie so far apart that they re-

volve about each other in a two-hundred year period. As Professor Moulton has suggested, if there are planets in this system, the phenomena of night and day must be curiously complicated.

The second magnitude star Algol, which lies about half way between the W in Cassiopeia and the familiar cluster of the Pleiades, is a double star of peculiar interest because one of the components is a dark body that chances to revolve in such a direction that it partly eclipses its bright companion. As it makes a complete revolution in less than three days, the fading out and rejuvenescence of Algol takes place in a period of a few hours during which the star sinks from second magnitude almost to invisibility and returns again to second magnitude. These changes may readily be observed with the naked eye.

On the opposite side of the pole star from Algol lies the very interesting constellation Lyra. The very bright star Vega enables one readily to locate this constellation. This star, as we have seen, chances to lie within a few degrees of the direction in which our solar system is drifting.

Near Vega is one of the most famous of double stars, known as Beta Lyrae, which changes its brightness by more than a magnitude in a period of a little less than thirteen days. It has been estimated to be a double with components 10,000,000 miles in diameter, and having respectively ten and twenty-one times the mass of our sun. These two colossal bodies revolve about a common orbit so small that the two stars, which are necessarily elongated by their mutual

gravitational effect, are believed to be practically in contact. This supposition does not do violence to the rule of Roche's limit, which prohibits solid bodies to maintain such close contiguity, for the calculations show that these stars, notwithstanding their enormous mass, have an average density less than that of air at sea level. Beta Lyrae is therefore in effect a double nebula; but to the mundane observer it appears as a single point of light.

Not far from this star there is a nebula of vastly greater proportions which belongs to the small group of ringed nebluae and is the only one of its class that may be seen through a small telescope. The interesting peculiarities of this nebula are brought out to advantage only by the largest instruments, but the amateur will find it well worth inspection even with a three-inch glass.

The central star in this nebular ring suggests that a gigantic solar system is here in process of construction. The ring may represent a mass of nebular matter that has failed to aggregate into a planet through lack of a nucleus of condensation.

IV

EXPLORING THE ATOM

IF you take a lump of dry salt between your thumb and fingers you may readily reduce it to an impalpable powder. If you were to dust some of the almost invisible grains of this powder upon a glass slide and examine them through a microscope, you would find that the smallest of the dust-like particles now seems rather like a rough and jagged piece of rock rather than like the infinitesimal thing it appeared to the naked eye. It is easy to believe that this fragment of matter is built up of smaller particles and is nowhere near the limits of divisibility.

If now you put a few drops of water on the slide, you will see the rock-like particle of salt fade away and dissolve into nothingness. It has become absolutely invisible. If the microscope you are using is a powerful one, this means that there remains no particle of the salt of the size of one-hundred-thousandth of an inch.

In point of fact, the portion of salt has now been separated into molecules so small that many millions of them must be massed together to form the smallest visible particle of matter. These molecules are in all probability moving about freely among the molecules of water. It is not quite absolutely certain as

to what are the precise relations that obtain between the particles of the salt and the particles of the solvent. The best authenticated theory as to what takes place is that which Svante Arrhenius, the famous Swedish chemist, put forward as long ago as 1887, and which has been more or less matter of controversy ever since.

In accordance with this theory, which is known as the ion theory, a portion at least of the molecules of salt are broken up in the process of solution into so-called ions, each or which consists of an atom charged with electricity. A molecule of salt as is well known, is composed of one atom of sodium and one atom of chlorine. In the salt solution, according to the theory of Arrhenius, each liberated atom of sodium would convey a unit charge of positive electricity and each liberated atom of chlorine a unit charge of negative electricity.

The ions would be free to move about in the solvent, and their capacity for such motion is demonstrated when an electric current is passed through the solution. In such an event, the positively charged ion is moved toward the negative pole, and the negatively charged ones toward the positive pole. The fact of such migration is demonstrated, in the case of solutions of metallic salts, in the familiar process of electro-plating, in which, as is familiarly known, particles of pure metal, copper or silver, are deposited at the negative electrode. It is believed that the ion in its migration carries with it a film of the solvent. The rate of migration was first measured by Sir Oliver Lodge, and various investigators have re-

peated and modified his experiments. It is shown that different ions move at varying speed, and that the rate of motion bears a certain relation to the atomic weights of the various atoms.

The ion theory was early championed and variously tested by Professor Wilhelm Ostwald, who not only viewed it in connection with his elaborate investigations of acids, but pointed out its relation to the theory of osmosis advanced at about the same time by the Dutch chemist J. H. Van't Hoff. According to this theory, the familiar but hitherto inexplicable phenomena of osmosis, in accordance with which water passes through a membrane from a less concentrated to a more concentrated solution, are due to the pressure on the membrane of the molecules in the solvent; which pressure, according to the theory, is precisely the same that would be exerted by a corresponding number of molecules making up an equal bulk of a gas.

The theory of Van't Hoff met with certain contradictions so long as the molecules of a salt were regarded as maintaining their stability in solution, but when these molecules were thought of in connection with the ion theory as split up into their component atoms, the theory harmonized with the observed facts. Thus the new ion theory of solution and the theory of osmosis tended to support each other. The fact that each ion of the disassociated molecule conveys a charge of electricity is the essential fact lying back of all chemical activity whatever. Thus the ion theory, or as it is also called the disassociation theory, is of fundamental importance in

chemistry. While it is not given universal assent, it finds support in an ever-widening series of observations.

THE ZEEMAN EFFECT

Regardless of theoretical explanations of the conditions that obtain in our salt solution, it is obvious that the particles into which the salt has separated in the process of dissolving are so small that they do not obstruct the light waves; otherwise the solution of which they now form a part would not be transparent. But if we were to thrust a platinum wire into the colorless solution and then hold the wire in the flame of a Bunsen gas burner, the flame will instantly take on a peculiar yellow color which proves to the discerning eye that the particles of salt have been rendered luminous. If this green flame is examined through a spectroscope, the rays of light coming from it will be observed to be split up into a characteristic series of lines.

This particular series of spectral lines would not appear in light emanating from anything but sodium. No other substance in the world can duplicate that record. The same series of lines might appear in the light coming from the sun or from a star; but they would prove the presence of sodium at the source of light.

These lines *spell* sodium in the language which any chemist in the world can read; and the signature of the spectrum cannot be forged or duplicated.

What is true of sodium is true of every other element. Each has a sign manual that it writes as

a series of lines in the spectrum. The chemical test thus afforded is exquisitely delicate. There may be but the smallest trace of a given substance present, as in the case of our infinitesimal droplet of salt solution, but the tell-tale lines of the spectrum will record the trace of this individual substance, even in the midst of many other substances.

If while examining our sodium flame through the spectroscope we were to hold the flame between the poles of a powerful electro-magnet, we should observe that the sodium lines which before appeared single are now split in two and separated. This phenomenon is called the Zeeman effect in honor of its discoverer, Professor Peter Zeeman of Amsterdam. It is a phenomenon of vast importance from the physicist's standpoint, inasmuch as it gives interesting clues to the activities of the atomic forces, and to the character of light.

This phenomenon of the splitting up of spectral lines has been observed by Professor George E. Hale, Director of the Mt. Wilson Observatory, in connection with the light emanating from spots on the surface of the sun. The observation shows that sun spots are powerful magnetic fields. Thus the sun spot gives a demonstration on a magnificent scale of physical laws that may be tested, changed only in degree and not in kind, in the laboratory.

Incidentally, Professor Hale's observation serves in a sense to explain the relation that had previously been observed between outbursts of sun spots—which are in reality gigantic volcanoes of gaseous matter—and disturbances of terrestrial magnetism.

Professor Hale thinks that the magnetic field may be due to the rapid flow, in a vortex current, of negative ions from the hotter gases at the circumference of the spot towards the cooler gases at the center.

A further interest attaches to the Zeeman effect (whether manifested in the laboratory or in the sun) from the fact that it demonstrates the close relationship between magnetism and light. In Professor Zeeman's words, it shows that light is an electrical phenomenon. Meantime our experiment with the sodium flame demonstrated, obviously enough, a close relation between the activities of molecules or atoms of matter and the origin of light itself.

LIGHT BEYOND THE SPECTRUM

A single experiment thus suffices to show curious and interesting relationships between the ultimate particles of matter and those manifestations of energy which we term light, electricity, and magnetism. Meantime it is matter of every-day observation that there is ordinarily the closest relationship between light and that other manifestation of energy termed heat.

It is no matter for great surprise, then, to be told that the different portions of the spectrum into which a beam of light is spread out show different degrees of temperature when tested by an apparatus of sufficient delicacy. It appears, in point of fact, that the dark lines in the spectrum are also areas of relative coolness, and that the spectrum may be charted by moving a sufficiently delicate heat measurer along it.

The instrument with which this feat of measuring infinitesimal gradations of temperature is accomplished is known as a bolometer, and was invented by the late Professor Langley of the Smithsonian Institution.

The principle on which the bolometer is constructed is that any change of temperature in a metal changes the capacity of that metal as a conductor of electricity. By using an excessively tenuous flattened thread of platinum for his conductor, and an exquisitely sensitive galvanometer to register the effects, Langley produced an instrument which will respond to changes of temperature so slight in degree that no one could reasonably have supposed them measurable. Indeed the feats accomplished by the little instrument are as incredible, not to say fantastic, as the feats of the spectroscope itself.

A generation ago instruments for physical research had attained a high stage of development; but to measure a change of temperature of one-thousandth of a degree was considered a remarkable feat. The layman will be disposed to admit that it is a remarkable feat. But the perfected Langley bolometer measures a change of one-hundred-millionth of a degree. It is competent to deal with the infinitesimal quantities of heat that come to us from such bodies as the moon and the brighter stars.

As a practical apparatus, the bolometer's chief use has been to test the precise quantities of heat that come to us from the sun. Langley himself used it for this purpose, and since his death Professor C. G. Abbott has conducted an elaborate series of experi-

ments, chiefly at the solar observatory at Mt. Wilson, to determine the "solar constant." He makes the solar constant 1.92 calories per minute per square centimeter of surface normal to the solar radiation at the earth's mean distance; but he strongly suspects that the radiation is variable to the extent of about 8 per cent. in the course of a few days. It is probable, therefore, that the "solar constant" is not a constant; and that our sun is a variable star. Knowledge of this variability of the sun as a heat-giver will perhaps ultimately be available in predicting weather conditions here on the earth as influenced by sun spots or other solar phenomena.

But aside from these practical results, very great interest attaches to the work done with the bolometer, in that it enables the observer to detect and measure the presence of waves of energy beyond the visible spectrum. Indeed, it appears that an important concentration of heat rays occurs in the dark region below the deepest red, although in a normal spectrum the greatest focus of energy is in the blue.

Langley was able with the bolometer to chart this infra-red region of invisible light, if the term be permitted. He not only tested its gradations of heat but showed that it is crossed by hundreds of characteristic cool bands comparable to the dark lines of the visible spectrum.

Meantime it had been discovered that the rays of light that chiefly affect the photographic plate are those toward the violet end of the spectrum, and extending into a region beyond the utmost visible portion of the violet. It had long been known that

the color red represents relatively long light waves, whereas violet represents short waves. It now became obvious that the eye detects only a small part of the series of ethereal vibrations, and that all radiant energy given off by a luminous body includes a long series of waves on either side of the visible spectrum, each series having its peculiar and characteristic effects.

THE PRESSURE OF LIGHT

This dissection of the ray of radiant energy was made, as we have seen, with the aid of the spectroscope. It is obvious, however, that an ordinary beam of light, before it is split up by a prism, must contain the entire series of waves of energy—heat waves, light waves, and ultra-violet waves—blended and intermingled. We have just seen that different portions of those waves may be tested by the thermometer (or by its more delicate counterpart the bolometer), by the eye with or without the aid of the spectroscope, and by the photographic plate.

But there is a joint effect of the waves of radiant energy which may be interpreted in terms neither of heat, light, nor photographic effect, but in terms of physical pressure.

The exquisitely delicate instrument which measures this effect is called the radiometer. It was devised by two American physicists, Professors E. F. Nichols and G. F. Hull, and it is in effect a more delicate modification of an apparatus first made by the English physicist Professor Crookes. The little instrument demonstrates that the waves in the ether

which are interpreted as heat or light or electro magnetism, and which are rushing through space at the speed of 186,000 miles per second, wash against any object that lies in their path with an actual pressure—manifesting themselves as a positive push, in addition to their other effects.

This is quite what one might expect, perhaps, were it not that the ether is so exceedingly intangible an entity—one dare not say substance. Clerk-Maxwell, the most famous student of the ether, did indeed declare, from theoretical considerations, that this push must take place. But between theory and demonstration there may be a wide gap, and it remained for the experiments of Professor Lebedew in Europe and of Professors Nichols and Hull in America, undertaken simultaneously but quite independently, to place the matter beyond dispute. Now we know that every ray of sunlight gives a positive push to any material substance it reaches, and that a similar push accompanies all other radiations.

And as every body not at the absolute zero of temperature—a degree of cold never yet attained in a terrestrial laboratory, and obtaining, if anywhere, only in the depths of interstellar space—is giving off radiations, it follows that all bodies are pushing and tending to repel all other bodies that their radiations can reach.

The instrument that has demonstrated the existence of this hitherto only vaguely suspected force consists of two discs of thin glass (one disc blackened, the other polished), suspended by a quartz thread in a vacuum. When waves of radiant energy impinge

on this delicate apparatus they disturb its balance, because the blackened disc absorbs the rays whereas the bright disc reflects them. So wonderfully delicate is the adjustment that a candle placed more than one-third of a mile away turns the vanes of the instrument through nearly one hundred scale-divisions. As one-tenth of a single division can be readily detected, it will be seen that a candle at this distance by no means puts the implement to its fullest test.

It is estimated that, were there no atmospheric obstruction, the candle could be detected at a distance of sixteen miles. The face of an observer can be detected at a distance of several miles; at two thousand feet it turns the vanes through twenty-five scale divisions.

So every human countenance glows as a beacon light, signaling out for miles in every direction—only one must be equipped with a radiometer if one would note or heed the signals.

Directed toward the sky, the radiometer proves adequate to the task of registering the radiant energy of the larger stars and planets. The experiments of Professor Nichols have sufficed to show that the radiation push of a star can not be definitely predicated from observation of its luminosity. Thus it was found that the planet Saturn has only about three-fourths the thermal effect of the star Vega; the star Arcturus produces three times the effect of Saturn; the planet Jupiter more than six times as much, —relations quite different from the relative brightness to the eye of these various bodies.

Very recently Professor A. H. Pfund of Johns

Hopkins University has perfected a thermal couple which, as a detector of heat, is more than ten times as sensitive as the radiometer. Used in conjunction with the 100-inch mirror of the new Mount Wilson telescope, this instrument would detect the heat of a candle sixty miles distant. It suggests interesting new possibilities of investigations. Doubtless in time extended observations will teach us important lessons about the nature of the various stars, as recorded by variations in radiation. Meantime, the proof that this radiant-push exists and is everywhere operative is in the highest degree interesting and important. For an ether wave that pushes with such force against anything with which it comes in contact must be a factor in the distribution throughout the universe not only of energy but of matter.

Professor Svante Arrhenius, the famous Swedish physicist, has estimated the size of a particle of matter which would be driven before the light waves, as particles of dust are driven before the wind. He believes that radiation pressure explains the phenomena of the comet's tail, of the sun's corona, and of the aurora borealis, the latter being due to the activities of electrified particles driven to the earth from the sun. Thus radiation is in a sense a counterforce to gravitation.

What gives the phenomenon chief interest from the present standpoint, however, is that it shows the tremendous energy of the atomic forces that send out the ether waves. A molecule or atom vibrating in such a way as to send off—at the rate of many billions per second, and at a speed of 186,000 miles

per second—waves powerful enough to drive relatively large particles of matter before them, must be in itself a center of energy of astounding power, notwithstanding the incomprehensible minuteness of its size.

All these studies of the different manifestations of energy point in the direction of the atom, and give us more or less vague estimates of the activities of this tiny structure. It remained for a new line of investigation to reveal the atom itself. The new observations came about through the discovery of substances having curious properties hitherto unsuspected but now familiar to everyone under the name of radioactivity.

A NEW TYPE OF RADIATION

The initial discovery of a radioactive substance was made by the French physicist Becquerel, through the accidental observation of the effect of the chemical called uranium on a photographic plate. The discovery of other radioactive substances, including radium, by Professor and Mme. Curie, quickly followed, and the strange new properties were studied by many workers, chief among whom is Professor Ernest Rutherford, now of Manchester University.

The essential phonomena of radioactivity consist in the giving off of rays capable of affecting the photographic plate and of penetrating opaque substances. The radiation comprises at least three different types of rays, which have been named alpha, beta, and gamma rays. It is now known that the alpha rays consist of relatively heavy particles which are in re-

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ality atoms of helium each carrying a double charge of positive electricity.

The beta ray is identical with the cathode ray which develops when electricity is passed through a Crookes' or vacuum tube.

The gamma ray is identical with the X-ray which is developed when a cathode ray strikes the walls of the glass receptacle. It is due to the impingement of beta rays on the particles of the radioactive substance itself, and it probably constitutes a pulsation in the ether of a kind analagous to the waves of light and electro-magnetism.

The alpha ray has been studied with great care and it has given up one secret after another. That the alpha particle is an atom of helium, is a startling fact. For helium is an *element* hitherto known as an inert constituent of the atmosphere. And to suppose that one element can be transformed into another is to suggest a restoration of the obsolete heresy of the alchemist. Nevertheless the demonstration is complete that the alpha ray does consist of helium atoms, and that it is precisely the same whether it emanates from thorium, from radium, or from any other known radioactive substance—however the fact may be explained.

COUNTING THE ATOMS

Of the many theoretical and practical considerations that attend the subject none perhaps has a greater interest than the experiments which have made it possible to isolate an individual atom and actually test its size.

The apparatus through which this seemingly miraculous feat has been accomplished, is known as the electroscope. It is an instrument which constantly serves the student of radioactivity. Even as compared with the spectroscope and bolometer and radiometer, it is an apparatus of extraordinary delicacy.

The spectroscope, as we have seen, reveals infinitesimal traces of a substance. It can show the presence of the minutest quantity of a gas in a tube that in ordinary parlance would be said to be absolutely empty. But even the best vacuum that the physicist is able to produce contains many millions of gaseous molecules to the cubic inch. So after all the spectroscope is dealing with a vast swarm of molecules when it performs its most delicate feats. But the electroscope, as just intimated, is capable, under certain circumstances, of detecting the presence of a single atom. The tests that it can apply are estimated to be 500,000 times more delicate than the finest tests of the spectroscope.

In principle the electroscope is simplicity itself. It consists essentially of two bits of gold leaf suspended loosely together. If these gold leaves are electrified their mutual repulsion holds them apart. But if the electricity is discharged they fall together. Under ordinary conditions perfectly dry air is a nonconductor of electricity; therefore a charged electroscope shows its leaves spread apart. If the atmosphere is electrified, or as the technical phrase is, ionized, it becomes a conductor and permits the electricity to escape.

The test which showed the ultimate capacity of the electroscope was made recently by Professor Ernest Rutherford. He connected an electroscope with a closed cavity having a small aperture on one side, and near this aperture he placed a surface covered with radium. A certain number of the alpha particles thrown out by the radium could enter the receptacle through the aperture. The radium was placed at such a distance that only three or four particles per minute, of the shower flying in all directions, would be shot through the little window.

It was found possible to adjust the electroscope to such a state of delicate responsiveness that the entrance of a single alpha particle discharged it.

Thus it was possible to compute the number of alpha particles that are sent out by a given quantity of radium in a given time. Other experiments conducted by Professor James Dewar, of London, have carefully measured the quantity of helium gas that arises from a given quantity of radium. It is obvious that the two experiments combined show the number of helium atoms that make up a given quantity of helium gas.

Now it has long been known that all gases under equal conditions of temperature and pressure, contain the same number of molecules. A molecule may contain one or more atoms, but this also is something that the physicist has long been able to compute. It follows that the physicist is now able, thanks to the test performed by Professor Rutherford with the electroscope, to compute the number of atoms in any gas of known chemical composition.

As most solid substances can be reduced to the gaseous condition in known proportions, the number of atoms in a given quantity of any solid may also be quite generally computed.

The figures revealed are utterly bewildering. Professor Rutherford found that a grain of radium gives off 36 billion helium atoms per second. A cubic centimeter of helium gas contains atoms to a number represented by this absurd row of figures: 2,560,000,000,000,000,000,000—which is read, I believe, two sextillion, five hundred and sixty quintillion.

The weight of a single atom is the part of a gram represented by a fraction having one for the numerator and for denominator 68 followed by 24 ciphers—carrying the count to octillions.

Of course such figures convey little definite meaning. Perhaps they serve, however, to give at least an inkling of the utterly incomprehensible smallness of an atom. Reflecting, then, that the electroscope is able to detect the presence of a single one of these atoms, we find ourselves in the presence of an instrument the delicacy of whose operation is little less than awe-inspiring.

We saw that the big telescopes, aided by the photographic plate, reveal stars to the number of at least one hundred million lying utterly beyond the confines of unaided vision. Now it appears that a pinch of salt that one could hold on the point of a penknife is made up of atoms numbering not hundreds of millions merely, but billions of billions. The population of atoms in the smallest particle of mat-

ter visible under the microscope is greater by far than the total human population of the globe since the race developed.

And a little instrument composed of two fragments of gold leaf makes it possible to perform the miracle of counting these denizens of the realm of infinite littleness.

SEEING THE INVISIBLE

Moreover there is a second method, also devised by Professor Rutherford, by which the helium atoms may be counted as they fly off in the form of alpha particles from radium; a method that seems even more wonderful than the other, because of its extreme simplicity and the fact that it depends upon direct vision.

The method consists of watching through a microscope a small portion of a screen covered with a compound of sulphide of zinc or willemite. This screen as originally devised by Professor Crookes, has the property of emitting sparks of light when bombarded by the alpha particles as they fly off from a radioactive substance. As ordinarily witnessed the bombardment suggests a shower of shooting stars; or it may be even better likened to the splash of raindrops on a dimly lighted pavement. The instrument is called a sphinthariscope.

Professor Rutherford adjusts a bit of radium near the screen in such a way that all the rays are shut off from it except those passing through a small aperture. He can then through a microscope count the splashes of light, each of which is due to the

impact of a single alpha particle. He can thus estimate accurately the number of particles given off by a known quantity of radium in a certain time as before. The result coincides with the other method of counting within the limits of errors of observation. Thus there is a check on the method of counting and measuring the atoms, and we may feel fairly sure that the bewildering result already given represents substantially the facts.

Although this method of counting the atoms depends upon direct vision, it must not be inferred that the observer actually sees the atom itself. What he sees is the commotion created among the particles of the sensitized screen when the atom dashes into their midst. When you fire a rifle ball into the smooth surface of a lake half a mile away, you see the splash of the water clearly enough, but of course you do not see the rifle ball itself. The effect is precisely similar when the splash of light caused by the alpha particle is viewed.

The alpha particle itself is as far beyond the range of vision even aided by the most powerful microscope, as a rifle ball would be at the distance of several miles.

To give a tangible idea of the hopeless invisibility of an atom, we may note that the smallest particle of matter visible under the magnifying influence of the most powerful microscope is of such dimensions that 50,000 such particles placed in line would be required to extend across the space of one centimeter (about two-fifths of an inch). If we calculate the cube of this number, we find that 125 thousand billion such

particles could be crowded into the space of a cubic centimeter.

But Professor Rutherford's census of the atoms, as just outlined, shows us that twenty billion times that number of helium atoms would exist in the form of gas in the same space. Of course the molecules of a gas are widely separated. So it follows that the smallest particle of solid matter visible through the most powerful microscope contains many times twenty billion atoms.

PHOTOGRAPHING THE ATOM

In 1910 Sir J. J. Thomson discovered yet another method of making individual atoms give visible evidence of their presence. The medium through which the record is transcribed is in this case the photographic plate. In a word, Professor Thomson literally photographs the atoms. His method of letting the atom transcribe its own record on the sensitive plate is by far the most delicate method yet devised of analyzing the constituents of a gas.

The gases to be tested are introduced in exceedingly small quantities into a glass bulb which is called a vacuum bulb because it is supposed to contain nothing at all. When an electric current is passed through this vacuum, the bulb glows with a peculiar phosphorescence, and the now familiar phenomena of the cathode ray are manifested. The cathode ray, as we have seen, consists of negative particles of electricity. It has now been shown that particles of another type traverse the tube in the opposite direction to that in which the cathode par-

ticles are streaming. A perforation being made in the electric cathode, these retrograde particles pass through the aperture and impinge on the glass bulb back of the cathode. Because of the method in which they are tested these rays have been called "canal rays" by the German physicist Goldstein who first observed them.

Sir Joseph Thomson tested these rays by subjecting them to the simultaneous influence of an electric current and a magnetic field. Electricity deflects them in one direction and magnetism in another, so that as a result they are diverted from their direct path and assume an elliptical orbit. The record of their divergent flight is instantaneously impressed on a photographic plate.

To casual observation the photograph suggests a shower of shooting stars or tiny comets, or in some cases an auroral display. But Sir Joseph Thomson has been able to demonstrate that each streak of light represents the flight of a particular type of atom, and that different atoms are deflected in degrees precisely dependent upon their atomic weight. The hydrogen atom, for example, being very light, is deflected more than the helium atom, and this in turn is deflected more than the still heavier atom of oxygen.

So here again the individual atoms are made to record their presence.

The method has great interest for the chemist because it enables him to detect the presence of quantities of a foreign gas too minute to be indicated by the spectroscope. The rays are registered within

less than a millionth of a second after their formation, and Sir Joseph Thomson suggests that when chemical combination or decomposition is occurring in the tube the method may disclose the existence of intermediate forms which have only a transient existence.

Already it has been shown that even an elementary gas may consist of a mixture of a great many different substances. In the case of oxygen, the photographs reveal no fewer than eight different forms of atoms and molecules, ranging from individual neutral atoms of oxygen to molecules composed of six atoms with a positive charge of electricity.

Thus the physicist not only photographs the atoms, but records their intimate transformations and combinations.

THE NEW ALCHEMY

All this is startling enough. But there are experimenters who believe that an even more wonderful kind of atom-juggling lies within the possibilities of the near future. Announcement made in London early in 1913 seemed to foreshadow the solution of the old problem of the alchemist—the production of gold in the laboratory. The paper which aroused these more or less visionary expectations was given jointly by Sir William Ramsay and Professors Norman Collie and H. Patterson before the Chemical Society of London at the meeting of February 6th, 1913.

Professor Ramsay spoke by way of introduction, and told of the finding of helium in a bulb which

previously had contained only hydrogen, through which an electric current had been discharged. Professors Collie and Patterson told of the discovery of the gas neon under like circumstances. The reputation of the investigators justifies the belief that all sources of experimental errors were excluded, and that a certain portion of the gases helium and neon actually made its appearance in a bulb which at the beginning of the experiment had contained only hydrogen.

This experiment seems by no means so startling as it would have seemed a few years ago. The phenomena of radioactivity have made us familiar with the transmutation of one substance into another. In particular it has been demonstrated, as we have seen, that the alpha particles which fly off incessantly from radium and various other radioactive substances are in reality molecules of helium, each conveying a double charge of positive electricity. So the appearance of the element helium as the by-product of another element is a phenomenon already clearly established.

But the peculiar significance of the new experiments just reported is this: the new substances are made to appear in the tube without the presence of any radioactive substance, and at the will of the operator, through the use of the electric current. What is still more remarkable, however, is the fact that helium and neon are both of higher atomic weight than the hydrogen in the midst of which they appear. Specifically the weight of hydrogen is placed at unity, whereas helium is four times as

heavy, and neon twenty times as heavy. At first glance, therefore, it would appear that the experimenters have been able, with the use of the electric current, either to cause hydrogen atoms to combine to produce heavier substances, or else have actually built up new elements out of electrons; or at the very least have caused helium to combine with oxygen from the glass walls of the bulb to form neon.

This would be a very wonderful transformation indeed, but it chances that the phenomena are susceptible of much less startling interpretation. Sir J. J. Thomson, the foremost authority on the subject, suggests that what has actually taken place is the driving out by the passage of the electric current of a certain number of molecules of helium and neon that were occluded in the platinum of the electrode. Professor Thomson had himself observed the production under similar circumstances of a new substance apparently having the atomic weight three, which could be explained either as a new element or as a new type of molecule composed of three hydrogen atoms. The possibility of the occlusion of alien molecules between the molecules of metals is fairly established.

Meantime, however, the possibility must not be overlooked that the elements neon and helium were actually driven out from the atomic substance of the plantinum electrode, or of the glass walls of the bulb, and if such were indeed the fact the experiment would have the very greatest importance. It would be demonstrated that it is possible by a means available in the laboratory to disrupt the atoms of a non-

radioactive substance. And this would clearly suggest the possibility that a means may ultimately be found to disrupt any and all of the elementary atoms.

It is an observed fact that the spontaneous disruption of the atoms of the very heavy substance uranium, through the throwing off of helium atoms, results in due course in so lessening the weight of the uranium molecule that it becomes a molecule of radium, and this in turn undergoes successive transformations associated with the throwing out of the helium atoms, leading, it is believed, to an end product that is the familiar substance lead. This substance shows no tendency to continue the process of disruption. But if an artificial means could be found to cause the atom of lead to throw out two helium atoms, we should have its weight reduced substantially to that of the atom of gold.

These are the facts which justify Sir William Ramsay in declaring that it seems within the possibilities that we shall ultimately be able to transform lead into gold. If Professors Collie and Patterson have accomplished what their more sanguine critics think they have accomplished, we are clearly one step nearer to this alchemistic miracle. In any event, the new knowledge that observation of the radioactive substances has given us, puts the possibility of such a transmutation of metals on an entirely new scientific footing. What the atomic chemistry of the nineteenth century seemed to prove impossible seems now to lie well within the bounds of credibility,—though doubtless still far enough from actual accomplishment.

THE SMALLEST THING IN THE WORLD

We have seen that the atoms which thus give up their secrets to the photographic plate are billions of times smaller than the smallest particle of matter that is directly visible under the microscope. It would seem, then, as if this recent feat of Sir Joseph Thomson, together with the spectacular demonstrations of Professor Rutherford, must carry us into the realm of the invisible almost to the limits of imaginable minuteness. But in point of fact there remains one other step that the physical investigators of our time have been able to take which would still further tax credulity were it not certain that the things recorded are the results of definite experimentation and not of mere day-dreaming.

The final feat of analysis to which I now refer is that which demonstrates that within the smallest atom there is a *something* almost two thousand times smaller than the atom itself,—a something that is detachable from the atom and susceptible of being measured as to its mass and tested as to its electric charge with the aid of the apparatus of the laboratory.

This ultimate particle of matter is called the electric corpuscle or electron. We owe our knowledge of it chiefly to Sir Joseph J. Thomson, of Cambridge University, England. It is the smallest thing in the world; and it is probably the basal substance out of which all matter of whatever character is built. Our present view of it must be confined to a brief reference to the manner in which it has been weighed and measured.

The electron was first revealed in the cathode ray which, as we have seen, is generated in a vacuum tube when electricity passes through it. The cathode ray, as such, consists of a stream of electrons driven off from the negative pole or cathode. The fact that these particles are deflected by an electric current shows that they are tangible substances, and the amount of deflection with a given current makes it possible to compute the charge of electricity they carry.

The electron appears again as the constituent of the so-called beta ray given off by a radioactive substance. Electrons may also be liberated from ordinary matter, when any substance is heated to a very high degree, or when rays of ultra-violet light impinge on a metal at ordinary temperature. Yet again they appear in ordinary gases when a heavy charge of electricity is forced through the gas,—say a lightning stroke. They are likewise liberated in a gas subjected to the X-ray or to the so-called gamma ray of radium.

It required a vast deal of experimenting to show that the electrified particles which appear under these diverse circumstances are in reality one and the same thing. The demonstration was made, however, and several means were found of testing the quantity of electricity which the particle carries and even of counting the particles themselves.

The simplest method of counting the particles is by passing the X-ray through a portion of air, and then allowing the air to expand in a receptacle. Expansion cools the air and causes the deposit of drop-

lets of water—in effect miniature dew drops—upon the electrons. The particles of water thus formed constitute a fog which begins to settle toward the bottom of the receptacle. The rate at which the particles settle can be determined by direct observation of the upper surface of the fog.

Heavy substances, as everybody knows, fall under influence of gravity at a fixed rate, regardless of size or weight. But minute particles, on the other hand, make their way downward through the atmosphere at a rate that varies with their size in accordance with a law named Stokes' law after its discoverer. This direct observation of the rate of settling of the particles of water condensed on the electron gives the size of the particles. Another computation shows the total amount of condensed vapor, so a simple division gives us the number of the droplets and hence of the electrons.

Then the total charge of electricity carried by all the electrons can readily be measured with the electrometer, and again all that is necessary is to divide this quantity by the number of electrons to find the quantity of electricity which each conveys.

The experiment shows that the unit charge of electricity carried by the electron is always the same. Professor R. A. Millikan, of the University of Chicago, has recently confirmed this by a series of ingenious experiments, in which he isolates a droplet of oil and observes it through a miniature telescope while it takes up one or more electrons from the air. His experiments permit him not only to measure accurately the electric charge of an electron, but to

deduce the number of molecules in any substance, the force of molecular energy, and the weight of the atom.

The experiments show further that the total mass of the electron is due to its electric charge. Stated otherwise, the electron it not merely a unit particle of electricity,—it is nothing but electricity. It is not matter in the ordinary sense of the word. It is a center of force, a concentration of energy, and may perhaps be thought of as a little whirl in the ether. It carries energy in a perfectly definite quantity, and must be thought of as occupying a definite position in space and having what might be called an atomic structure.

But the amazing thing is that its mass is found to be about 1700 times smaller than the mass of the hydrogen atom which had hitherto been the smallest thing of which the imagination of men of science had taken cognizance.

We have already reviewed mystifying rows of figures showing us that the helium atom is trillions of times smaller than the smallest particle visible under the microscope. Yet we know that this helium atom is four times as large as the atom of hydrogen. And now it appears that the electron is 1700 times smaller still. It taxes the imagination to conceive even in the vaguest way the all but infinite littleness of the helium atom; yet to build up the structure of one such atom, judged by standards of mass, would require almost 7000 electrons.

As regards bulk, the electron is, according to the French physicist, Jean Becquerel, billions of billions

of times smaller than the atom. To make the comparison vivid, Becquerel likens the electrons in an atom to a swarm of gnats gravitating about in the dome of a cathedral.

THE STRUCTURE OF THE ATOM

Some imaginative physicists think of the electrons as making up planetary systems within the atom, and as circling about with infinite speeds in orbits differing only in their infinitesimal smallness from the orbits of planets and stars of the visible universe. Other physicists caution us against drawing too close analogies between the stellar and atomic systems. But all are agreed that the activities of the electron, whether thought of as orbital or as vibratory, are enormous.

Sir J. J. Thomson estimates that an electron once dislodged from its atomic system, may dash hither and thither from one atom to another at such speed as to change its location forty million times in a second.

Be that as it may, the demonstration seems complete that the activities of the electron and these alone produce the manifestations of energy which we interpret as light, radiant heat, and electricity. All chemical action is likewise held to be due to the activities of the electron. It is suspected that gravitation is of the same origin.

The electron which thus seems to be responsible for all manifestations of energy, is regarded by many physicists as the sole constituent of matter. Different kinds of atoms, in this view, differ from one

another only in the varying number or diverse arrangement of their component electrons.

This extreme view is perhaps hardly justified; but on the other hand it appears to be established that electrons are associated with every kind of matter, and there is good reason to think that an electric current consists essentially of a flight of electrons along a conductor. Incandescent metals and metals treated with ultra-violet light give out electrons. Professor B. W. Richardson, of Princeton University, in recent experiments with filaments of the metal tungsten at high temperatures in a vacuum, has proved that the emission of electrons may be a physical rather than a chemical process, and that the electrons actually flow into the tungsten filament, along electrical conductors, from outside the vacuum bulb. He has thus furnished what is regarded as direct experimental proof of the electron theory of conduction in metals.

It seems speaking well within bounds, therefore, to say that this inconceivably minute particle, which is far and away the smallest thing of which present-day science has any positive knowledge, is at the same time far and away the most important thing in the universe.

THE ALL-PERVADING ETHER

As we penetrate thus far and farther into the realm of the infinitely little, seeing in imagination the smallest visible particle of matter resolved into myriads of molecules; each molecule into sundry atoms; and each atom into its teeming swarms of

electrons, the question naturally arises, What lies beyond?

The answer is that, so far as present-day science knows, the electron is the last term of the series. As the mind cannot grasp the conception of empty space, physicists imagine an all-pervading ether, permeating everywhere between the particles of matter, and serving as the medium of communication whereby energy is transmitted from one particle of matter to another throughout the universe. Light, electricity, magnetism, radiant heat, are various manifestations of energy transmitted, so it is believed, in the form of waves in the ether.

This ether, as the physicist conceives it, has neither weight nor discrete substance. It is the unique all-pervading something that is neither energy nor matter. Its importance from a human standpoint may be summarized in the statement that but for the ether neither light nor heat would come to us from the sun.

When we reflect that the ether is supposed to penetrate everywhere between the particles of matter, and that material substances, so far as experiment goes, move through the ether without being in the remotest degree obstructed, it will be obvious that this all-pervading medium is an ever-present mystery. It has been a puzzle to surmise how the particles of matter could produce waves in a medium which seemed in no wise to obstruct the activities of these particles.

But now it appears that the link between the structureless ether and matter with its atomic struc-

ture is found in the electron. This infinitesimal particle, according to the theory of Sir Joseph Thomson, grips the ether somewhat as material substances grip the air, and its activities set up waves in the ether that are as tangible as the waves that radiate out from a pebble dropped into the smooth surface of a pond.

The ether waves set up by the electron vary in length or degree of agitation. But they move through space at a uniform rate of speed which has been demonstrated to be about 186,000 miles per second. Waves of a certain degree of agitation we interpret as heat; waves of another order we interpret as light—red light or green or yellow or blue or violet, accordingly as the waves are longer or shorter. Still shorter waves produce ultra-violet light, which affects the photographic plate, but is invisible to the eye. Waves of yet another order—excessively long waves, namely—constitute electro-magnetic currents, such as are used in wireless telegraphy.

But, according to the view of present-day physics, no one of these sets of waves would agitate the ether were it not for the activities of the electrons which, grouped in various fashions, are hurtling hither and thither within the structure of every atom of matter, or are dashing at break-neck speed from one atom to another.

It remains to be said, however, that there has been a tendency in very recent years to challenge the wave theory of light notwithstanding the seemingly secure position it has held for the better part

of a century, and to question whether the manifestations that have in recent generations been interpreted as undulations in the ether may not be susceptible of another interpretation more in keeping with the old idea of Newton that light really consists of infinitesimal particles hurtling through space. This reactionary conception, which as yet is only vaguely formulated, is obviously in keeping with the studies that have carried us from the molecule to the atom and from the atom to the electron; the conception, in short, which tends to visualize all matter, and even energy itself, as in the last analysis corpuscular in character. Even the all-pervading ether has been brought within the scope of this conception by the newest theories, as will appear in a moment. We may well complete our survey of the world of the infinitely little by passing on to a brief examination of the newest theories as to the nature of the ether; which theories, as will appear, involve also an attempt of an even more fundamental character than any hitherto suggested to solve the problem of the ultimate nature of matter itself and of the perennial mystery of that hitherto inexplicable force which is observed to operate everywhere and always between the particles of matter and to which we give the name of gravitation.

FROM MICROCOSM TO MACROCOSM

In attempting to follow this newest exploration of theoretical physics we are confronted by an astounding paradox. This is nothing less than the assurance that what we call matter is really the least substan-

tial thing in the universe, and that what we are accustomed to think of as the absolutely immaterial ether is in truth a structure of enormous density. Yet this conclusion is arrived at along different lines of reasoning, and it is one upon which the most authoritative physicists are agreed.

Thus Sir J. J. Thomson assures us that the unit particle of electricity, called a corpuscle or electron, owes its mass entirely to an infinitesimal quantity of ether which is in some way bound up with its substance; and as all matter, in his view, is supposed to be built up of electrons, it follows that "all mass is mass of the ether, all momentum momentum of the ether, and all kinetic energy kinetic energy of the ether." Professor Thomson then goes on to assure us that "since we know the volume of the corpuscle as well as the mass, we can calculate the density of the ether attached to the corpuscle; doing so we find it amounts to the prodigious value of about 2,000,000,000 times that of lead." He adds, however, that this would be the density of the ether only in the immediate vicinity of the electron or corpuscle and that its density elsewhere in space would be considerably less, if the ether is compressible.

To make somewhat comprehensible the paradox that matter as we know it is able to move freely in a medium of such density, Sir Joseph Thomson gives us this illustration: "Although at first sight the idea that we are immersed in a medium almost infinitely denser than lead might seem inconceivable, it is not so if we remember that in all probability *matter is composed mainly of holes.* We may in fact regard

matter as possessing a bird-cage kind of structure in which the volume of the ether disturbed by the wires when the structure is moved is infinitesimal in comparison with the volume enclosed by them. If we do this no difficulty arises from the great density of the ether. All we have to do is to increase the distance between the wires in proportion as we increase the density of the ether."

It undoubtedly puts a strain upon the ordinary imagination to conceive of the existence of this all-pervading medium which gives to our senses no evidence of its existence. But the paradox becomes still more startling when we turn to the newest theory as to the exact nature of this etherial medium. This is the theory elaborated by the late Professor Osborne Reynolds, of Owens College, Manchester, England, which has recently been called to the attention of the American public through an interpretation given by Professor John Mackenzie, of Minneapolis. According to this theory, which is supported by a mass of mathematical reasoning which the average reader must take on trust, the ether is composed of spherical granules of such infinitely small size that 700,000,000,000 of them placed in line could lie in the trough of a single wave of violet light; said wave of light being about the one-seven-thousandth part of an inch in length. These granules, according to Professor Reynolds' theory, are the ultimate or primordial atoms, perfectly spherical, and absolutely rigid. They are almost infinitely small as compared even with the size of the electron, which we have seen to be almost infinitely small in comparison with

the atom. And the atom, it will be recalled, was until recently supposed to be the smallest thing in the universe.

But all recent research has seemed to suggest that objects in nature become important in a progressive ratio as they become smaller. This rule of thumb applies with full force to Professor Reynolds' primordial granule. For according to his theory the entire material universe as we know it—that is to say the entire universe of matter—consists essentially of *little maladjustments or flaws in the universal granular ether!* In this view, what we call matter is not the substantial but the unsubstantial part of the universe. Like Sir Joseph Thomson, Professor Reynolds calculates that the all-pervading ether is vastly more dense than any material substance,—his calculation makes it 480 times denser than platinum,—and he likens matter to bubbles in this dense medium. Professor Mackenzie has this to say by way of interpretation of this paradox:

"You have all seen bubbles moving in water. Reynolds shows that the earth and all other material bodies move through space in a similar manner. They are less dense than the medium in which they exist, and their movements are due to differences of pressure in the surrounding medium. They are like so many filmy soap bubbles which a child blows from the stem of a pipe. Real mass is not in the material things which we see, but in space where the eye sees nothing. The sober conclusion of the most advanced dynamical science is that matter is a negative thing so far as its mass is concerned, and that the space

occupied by 'matter' contains very much less than the space where no 'matter' exists."

I shall not attempt here to detail the reasoning by which this paradoxical view is sustained and made to seem plausible. Suffice it that spherical bodies of tangible size, say shot or marbles, can be piled together in various ways, and that accordingly as they are piled in so-called dilated or in close order, they occupy more or less space. From the experiments with such tangible spheres, it is shown that a shift in the mutual positions of the hypothetical granules making up the ether will account theoretically for the production of rifts or bubbles which our crude senses interpret as solid matter, and that an extension of the same reasoning makes possible an explanation of the world-old mystery of gravitation itself.

The observations that led Reynolds to his explanation of gravitation are based on tests made with masses of small granules, such as shot or sand grains, and have to do with the phenomenon which Reynolds describes as dilatancy. This "consists in a definite change of bulk, whenever there is a definite change of shape or distortional strain, any disturbances whatever causing a change of volume and general dilation."

Professor Mackenzie illustrates the meaning of this by saying that when shot or sand or other spherical grains are put into a bag or other closed surface and shaken, they settle into a very close position, in which the spaces or interstices between the grains are about the smallest possible. This

would be described by Reynolds as "normal piling," and in such a case the "bag containing the shot or grains can not be changed without at the same time changing its bulk or volume, because if you shift the mutual relations of the shot, they roll into such positions as to increase the interstices between them.

Interesting experiments are shown by Professor Mackenzie, in which a bag filled with sand and water has inserted into it a brass tube connecting with a mercury pressure guage and on the other side of the bag a connection with a rubber tube leading to a glass tube filled with colored water. When a pressure of 200 pounds is applied to the sides of the bag, the mercury guage shows that notwithstanding the great pressure on the outside of the bag, the pressure inside the bag is reduced. The same thing is proved in another way by closing the pressure guage and opening the valve in a rubber tube which connects the bag with the glass tube filled with colored water. When pressure is applied to the bag as before, the colored water falls in the glass tube and passes into the bag until nearly a pint has been drawn in. "One would think," says Professor Mackenzie, "that the pressure on the outside of the bag would squeeze anything that was in the bag out of it, but these experiments show that the reverse is actually the case, due to the dilation of the granular medium."

Practical experiments such as this put Reynolds on the track of his explanation of the cause of gravitation. He argued that if the ether, consisting of infinitesimal granules in normal piling, extends indefinitely in the universe, there can be no mean motion

of the boundaries whatever the pressure may be at any part of the structure. The grains are virtually within a closed surface. Any change in the piling of their granules, then, must result in increasing the spaces or interstices between the granules, just as in the case of the sand bag. And it is these spaces, which in Professor Mackenzie's experiment were filled with colored water drawn into the bag, which in the mass of ether granules constitute fissures, or, in Reynolds' words, "singular surfaces of misfit." In everyday terminology these are particles of matter. Such particles or gaps form "surfaces of weakness," and it is shown that the pressure of the medium is less between those "negative inequalities" or surfaces of weakness than it is on the outside. There is a strain set up in the granular medium which produces a curvature in the normal piling. And it is this "strained normal piling" that produces pressure which we interpret as gravitation.

"Strained normal piling," says Reynolds, "implies that, although the shape of the medium is strained, so that the distances of the grains from their twelve neighbors [each spherical granule is in contact with twelve others] are no longer equal—since the successive layers of grain in the normal piling instead of being flat are subject to slight spherical curvature —the strains are such as do not allow any change of neighbors; so that when the strain is removed each grain will find itself in normal piling with the same neighbors."

It is because of this curvature in the medium that the pressure is less between the "fissures" that con-

stitute matter than it is in the medium outside, and hence that the fissures or particles of matter are pressed toward one another,—such pressure constituting what is commonly known as the attraction of gravitation.

Thus it appears that the theory conceives two kinds of strain in the granular medium, one producing fissures that constitute matter, and the other a maladjustment that results in pushing the fissures toward one another. The entire subject is too abstruse to be clearly grasped as to its details without much study, but the general fact of a mechanical interpretation of the structure of the universe and of the mystery of gravitation,—and, it may be added, of electricity and magnetism as well,—gives Professor Reynolds' theory a high degree of interest and importance. But of course it must be recalled that this interpretation of the nature of the ether is as yet altogether hypothetical and not at all comparable in validity to the facts and theories concerning the molecule, the atom, and the electron with which the earlier pages of the present chapter were concerned.

V

JUGGLING WITH LIFE

POSSIBLY the reader recalls Huxley's famous demonstration that old maids are largely responsible for the development of the beef-fed Briton. The explanation was that old maids are the keepers of cats; that cats destroy field mice; that field mice in turn, if allowed to live, would destroy the bumble bee, and that the services of this insect are required in the propagation of clover,—upon which feed the oxen that supply food to the Briton.

Notwithstanding the facetiousness of this chain of reasoning, it nevertheless conveys an important truth: the truth namely that the very existence of flowering plants is dependent upon the friendly services of insects.

Before the day of Darwin it was pretty generally supposed that flowers are provided to gladden the eye of human kind. Darwin showed that the real purpose of the blossom is to attract insects, in order that the pollen may be conveyed from one flower to another and the fertilization effected without which no seed or fruit can be produced.

The fragrance of flowers and the presence of sweet juices are designed to accomplish the same end. When, therefore, we hear bees humming about the

apple blossoms, we may rest assured that provision is being made for a good crop of fruit the coming fall. And everyone who has lived in the country must have observed that protracted rain storms just at the time when the apple trees are in bloom may keep the insects from performing their unconscious service, and thus may prevent the possibility of a good apple crop that year.

These familiar illustrations from the vegetable world suggest—what indeed is matter of common knowledge—the almost universally prevailing plan of Nature according to which the union of two diverse types of elements is essential to the production of offspring. Every-day phraseology speaks of these as male and female elements. The biologist, using the same terminology for animals and plants, calls the female element an ovum or germ cell and the male element a spermatozoon or sperm cell.

Biologists and laymen have been at one in supposing the union of the two elements to be absolutely essential to the development of offspring in the case of higher organisms, with the exception of certain insects about which we shall have more to say in a moment.

CAUSING UNFERTILIZED EGGS TO DEVELOP

Hence the astonishment with which scientific and unscientific readers alike received the intelligence, in 1899 and 1900, that one of the most painstaking investigators among contemporary biologists, Professor Jacques Loeb, then of the University of Chicago, later of the Rockefeller Institute, New York, had

succeeded in causing the eggs of a relatively high organism, the sea-urchin, to develop without fertilization.

The method by which Professor Loeb had effected this astonishing result was a relatively simple one. It consisted essentially in rendering the water in which the eggs were kept more concentrated by the addition of chemicals no more mysterious than common salt. As finally perfected, the process was a trifle more complicated, inasmuch as the egg was first placed for a brief period in a weak acid solution before being subjected to the influence of the salt solution. The acid causes the formation of a membrane which ordinarly does not develop excepting in a fertilized egg. The salt solution extracts a certain amount of water from the cell and in so doing inaugurates mysterious chemical changes that result presently in the development of an embryo which advances, for a time at least, as if the egg had been fertilized.

Professor Loeb's experiments were repeated by various investigators, and more recently it is reported that a French biologist has extended the process to even higher organisms, and with the use of a platinum needle and electricity has been able to cause the development of unfertilized eggs of the frog. This proof that even the egg cell of a vertebrate may be caused to develop without fertilization is highly interesting, suggesting as it does that there is probably no limit to the possible extension of the method; but the newer experiments are only an amplification of the earlier demonstrations. Profes-

PROFESSOR JACQUES LOEB IN HIS LABORATORY

sor Loeb himself in 1912 extended his tests to the eggs of the batrachian, and caused unfertilized eggs to hatch and develop into tadpoles. In one case the animal was carried past the tadpole stage, and assumed the contour of the mature frog. It gave full promise of attaining maturity, but unfortunately it met an untimely end by drowning.

Experiments of this character assuredly break in on the ordinary course of biological events. Yet they are not altogether without natural precedent. The very lowest orders of organisms, such as protozoans and bacteria, habitually reproduce their kind by mere cell division. Even such highly developed organisms as the honey bee may produce offspring parthenogenetically. Indeed, it is well-known that the male bees are habitually so produced. It is only the "workers" of the hive that have two parents.

Notwithstanding these familiar facts of life in the apiary, and facts of similar import regarding certain other insects, the experimental development of unfertilized eggs in the case of the sea-urchin and the frog must strike the thoughtful observer as being essentially mysterious. So far as known, unfertilized eggs of sea-urchins and frogs never do develop in the ordinary process of Nature. The provision that every individual shall have two parents, and represent the blending of two sets of tendencies, is so nearly universal that it has come to have the force of a profound natural law, notwithstanding the exceptions just noted; and the artificial infringement of that law suggests a very interesting juggling with personalities.

It is obvious that the individual sea-urchin or frog developed from an unfertilized egg must lack an entire series of tendencies that come to the normal individual through the paternal strain.

TWO LIVES FOR ONE

The individual developed from an unfertilized egg must thus be thought of as having a somewhat restricted personality, owing to the fact that it has only a single parent. But what shall we say of the converse case in which an egg which would normally develop into a single individual is bi-sected and made to develop into two individuals?

This no less interesting juggling with personalities has been likewise shown to lie within the possibilities of laboratory experiment. Dr. Hans Driesch, working at the Marine Biological Laboratory in Naples, juggled with the eggs of even so relatively highly organized a being as the fish in this curious way. It is well known that the original egg cell, which marks the first stage of development of every living organism, high or low, begins its development after fertilization by dividing into two cells. These two cells divide presently into four; the four into eight, and so on.

In a word, the entire development of any organism consists essentially merely of the formation of more cells by division of pre-existing cells. The cells ultimately become modified and differentiated into various tissues, but their potentialities of development are all pre-existent in the original egg cell.

Dr. Driesch's experiment consisted in invading the

domain of the organism at the early stage when its original cell had divided into two, or had undergone a second, or even a third division. Left to its own devices, and under the influence of the laws of normal development, the egg which now consists of, let us say, four cells, would develop into a single individual fish. The four cells are as much parts of one individual as are the arms and legs of any given man parts of one individual.

Yet Dr. Driesch succeeded in teasing these four cells apart and saw each one of them begin life anew, as it were, as a separate individual.

And in due course each of the four developed into a complete and normal fish, differing in no obvious way from other fish of the same species except that they were smaller in size. The fact of reduced size, however, gives emphasis to the feeling, which one cannot well escape, that the four fish represent what might be spoken of as a multiple personality, and that each individual lacks something of a complete and normal inheritance.

In similar experiments with sea-urchins, Professor Loeb found that the embryo might be bi-sected after it had reached the sixteen-cell stage; each part developing into a complete individual.

THE CASE OF TWINS

It is of interest to note that the laboratory experiment whereby the miracle is thus performed of dividing one individual into two or four complete individuals, is duplicated in human experience in the case of what are spoken of in common parlance as

"identical" twins. It is matter of familiar experience that human twins are occasionally born that are so closely similar in all their physical and mental traits as to be distinguished with difficulty one from the other. Such twins, in the view of the physiologists, have been developed from a single ovum, by some accidental duplication of the laboratory experiment just related.

These identical twins are always of the same sex, and we may think of them as representing, like Dr. Driesch's fishes, a curiously divided personality. According to the normal scheme of things, they represent the hereditary potentialities of a single individual masking in the guise of two physical organisms.

The same comment obviously applies in even greater degree to the well-known cases in which the bodies of twins are not altogether separated; the best known of such cases being that of the Siamese twins. This condition also has been duplicated in the laboratory, where by retricting the embryo of a sea-urchin without actually bi-secting it, Professor Loeb has developed two adult organisms joined together by a bridge of tissue.

The constriction of the embryo is effected in a curious way in Professor Loeb's experiment with the sea-urchin. The egg is put into diluted sea water, and the weakened salt solution causes the egg to burst because of its osmotic pressure. Part of the egg content flows out without becoming detached from that which remains within the cell. The ruptured cell-wall itself serves as the constricting agent, and a dumb-bell shaped embryo is formed.

According to the amount of constriction this dumb-bell mass may expand and become rounded in form, in that case developing a single individual; or the constriction may continue and Siamese twins will result.

ONE LIFE FOR TWO

Not content with splitting one individual into two, biologists have attempted successfully the opposite experiment of fusing two individuals into one. Dr. Driesch, at the Marine Biological Laboratory at Naples, forced two embryos together at an early stage, and caused their contents to blend. A single giant embryo was thus produced. Professor Loeb repeated this experiment, and was able to fuse more than two eggs of the star fish, so that a single individual developed where there should have been two or three individuals. As in Dr. Driesch's experiments, the resulting individual was much larger than the average normal individual.

It seems more than likely that this observed development of abnormally large individuals by the fusing of egg-cells, may give a clue to the otherwise inexplicable appearance now and then of a human giant, the offspring of normal parents. The accidental fusing of two ova may produce a giant, just as the accidental division of an ovum produces identical twins.

In any event, the experiment of blending two or more individuals in the laboratory to produce a single individual suggests interesting questions as to the personality and hereditary potentialities of the

being thus produced. If the divided cell may be thought of as producing severed personalities, then the fused cells certainly suggest a blending of personalities that is no less interesting. The individual that has resulted from the actual fusing of the substance of two individuals, even though he presents only the normal number of physical organs and members, must assuredly have certain hereditary potentialities over and above the average of his fellows, inasmuch as each one of the offspring of the same parents differs somewhat from all its brothers and sisters.

That giants of extreme size are usually below the average in quality of mind and body, suggests the possibility that such abnormal individuals have resulted from the union of two or more ova of divergent tendencies,—even of different sexes,—representing, therefore, qualities too divergent for harmonious blending. The experimenters of the future will perhaps find the investigation of this question a fertile field.

NEW HEADS FOR OLD

The experiments that thus make one individual into two or two individuals into one, find an interesting counterpart in experiments of another type which are concerned with the regeneration of lost members. Here the tests are made on adult organisms, but for the most part the creatures experimented upon belong to low orders.

It is only creatures of the scale of development of worms, for example, that can be induced to grow new

heads when they are decapitated; the reason being, perhaps, that higher organisms have developed a concentration of nerve cells in the head,—as ganglia or brain,—so that decapitation involves a nervous shock from which the animal does not recover.

In the case of various worms, however, it is possible to sever the head without destroying the life of the individual. In such case, as Professor T. H. Morgan in particular has shown, a new head may grow closely duplicating the old one, and the individual may appear to be no worse for the experience. In the case of a certain type of flat fresh water worm known as a planarian, Professor Morgan has cut off both extremities, leaving only an oblong central section of the body; and has observed a complete restoration of both head and tail.

Professor Loeb decapitated a marine planarian (*Thysanozoön*), with the result that the head grew a new body and the body a new head, so that one adult individual had now become two individuals. Indeed this experiment by no means shows the limits of the capacity for rejuvenation of this type of worm. For Professor S. J. Holmes reports that he has cut a planarian into twenty pieces, each of which regenerated into a complete planarian of reduced size. The process was repeated over and over until hundreds of individuals had been produced, the last "generation" of which comprised individuals less than one-fifteen-hundredth of the bulk of the original individual.

Reflect that the planarian is a creature having eyes, a nervous system, and a fair equipment of internal

organs, and it will be obvious that this series of experiments resulted in an amazing multiplication of personalities.

Experiments of this type may be so modified as to result in growing multiple heads on a single body. Professor T. H. Morgan has been able to produce a two-headed earth worm, by cutting off the anterior end and then excising a piece of the central nerve cord, so that two anterior nerve ends remained, from each of which a head developed. Dr. Van Duyne, at Professor Loeb's suggestion, extended the experiment to planarians with such success as to grow not merely two but as many as six heads to an individual, each head with its normal pair of eyes.

Possibly the ancient Greeks were led to conceive the idea of the hydra-headed monster from observation of a planarian that through some accident had been similarly led to develop multiple heads.

As showing that the diverse heads thus developed on one body have in truth something of divided personality, we may note Professor Loeb's comment that his double-headed planarian is observed to develop conflicting tendencies. Thus the two heads will struggle for the same piece of meat, regardless of the fact that the same body will receive it whichever mouth wins.

Again the two heads may pull in opposite directions so strongly as actually to tear the body asunder!

This growing of hydra-headed monsters is curious enough, but Professor Loeb has juggled with certain other low organisms in a way in some respects even

more curious, undertaking to bring about the substitution of one organ for another. He applied his test to certain marine forms known as hydroids and ascidians with entire success.

There is, for example, a hydroid that is called a *tubularian* because its body consists of a long tube, one end of which is attached to the sea bed by a stolon or foot, while the other end, representing the head, is a fringe-like mass of tentacles with a mouth for the ingestion of food. Professor Loeb cut off both ends, and inverted the tube so that the end from which the head would normally grow was fixed in the sand, the foot end being free in the water. Under these circumstances a new head forms where the foot had normally been. It is even possible, in some cases, to develop a head at each end of the stem.

This process of so-called heteromorphosis is illustrated in a striking way, as Professor Herbst has shown, in the case of a creature much higher in the organic scale, namely, a crustacean, allied to the familiar crab. Here if an eye is removed, the severed organ may be replaced by an antenna. Indeed this is sure to take place if the optic ganglion is removed. On the other hand if this ganglion is left intact, a new eye is formed apparently quite as good as the old one.

RESTORING LOST MEMBERS

The growing of a new eye of this highly specialized type is a striking phenomenon. But it must be recalled that the crab and its allies have remarkable properties of regenerating lost members. It has long

been known that if a crab or a lobster loses a claw, another claw presently grows in its place. A similar restoration of members may take place in animals still higher in the organic scale. If a salamander, for example, loses its tail or a leg, the member is presently replaced by a new one precisely like the old. Various reptiles are also able to grow new members.

On the whole this regeneration of limbs would perhaps not seem mysterious—except as all life processes are mysterious—were it not that the capacity is entirely lacking in all organisms higher than the reptiles. No bird or mammal, either in a state of nature or under the observation of the experimenter, shows the slightest capacity to reproduce a lost eye or leg, or even the single joint of a toe.

It is this fact that makes the power of regenerating lost members as exhibited by the lower organisms seem mysterious and wonderful.

Inasmuch as the higher organisms have developed from the lower forms, it would appear that the capacity to restore severed members is one that has somehow been lost in the process of evolution. Interesting questions might arise as to just why this has come about. It is not altogether a question of complexity of organization, for the leg of a mouse, for example, is seemingly no more complex a member than the leg of a salamander. Indeed the two members are constructed after the same pattern.

Perhaps the explanation of the anomaly is to be found in the difference of habit of cold blooded and warm blooded animals. The cold blooded creatures are able to go long periods without food. They very

generally haunt secluded crevices and lie in wait for their food, consisting largely of insects or small worms and the like. The loss of a leg might not jeopardize the life of such a creature in any such degree as the life of a mouse must be jeopardized by a similar loss. Natural selection, therefore, may preserve the capacity to grow new members in the case of a cold blooded animal; through the same agency the capacity has been lost in the case of warm blooded animals.

But whatever the explanation, the fact remains, and we should think it almost miraculous were a mammal observed to grow a new leg in place of one that has been amputated.

Very recently, however, Dr. Alexis Carrel, of the Rockefeller Institute, New York, has shown that the lost members of a higher animal may be replaced by the substitution of a new member through a surgical procedure. He has amputated the leg of a dog, for example, and replaced the member with a closely similar one taken from another dog; and has seen the new member grow into place and become a part of the body of its new host.

Dr. Carrel has similarly transplanted various internal organs, including the kidneys, from one animal to another, and caused them to take root, as it were, and perform their normal functions. The success of his experiments is due largely to his introduction of a new method of uniting arteries and veins, whereby they are so cleverly sutured together that scarcely a trace of the point of union remains when the wound has healed. In recognition of the importance of this

method and its results, Dr. Carrel received the Nobel prize in medicine and physiology in 1912.

MULTIPLE PARENTAGE

From the present standpoint perhaps the most interesting application of Dr. Carrel's method of transplanting organs has been made by Professor William E. Castle, of Harvard University. Professor Castle has experimented in the breeding of guinea pigs, until he has developed white races and black races of these animals which always breed absolutely true. The experiment to which I refer consisted in removing the ovaries of a white guinea pig and replacing them with the ovaries of a black individual. The white individual—mated with an albino—thereafter produced black offspring.

It would therefore appear that the maternal heritage of these black offspring came from an animal that did not bear them,—an animal that had perhaps died long before. Meantime, it would be a misuse of language to deny motherhood of the offspring to the white guinea pig that did actually bear them.

Shall we say, then, that the offspring had two mothers?

If so, we are led to consider the question of personality from a new angle; for an organism with three parents is an anomaly that lies outside the domain of antecedent observation or experience anywhere in the organic world.

In yet another way the question of personality arises in connection with these new experiments of transplanting organs or members from one individual

to another. Dr. Carrel's observations show that there is a specific quality about the tissues of an animal that is profound and individual. The kidney of a cat seems to perform identically the same function as the kidney of a dog. But one cannot be substituted for the other in these experiments in transplanting members. The kidney of a dog may be transferred to another dog; the kidney of a cat to another cat; but the two must not be interchanged.

Even where the organ experimented with is so simple as the tube of an artery, it is with difficulty that an exchange between animals of different species may be effected. To all casual observation, and even to close observation with the microscope, the artery of a cat seems identical with that of a dog; but there is a deep-seated chemical difference which makes itself felt if, for example, a section of cat's artery is made to replace an exsected portion of the artery of a dog.

It was a foregone conclusion, therefore, that the attempt recently made by a Berlin surgeon to replace a diseased human kidney with the kidney of a monkey would be a failure. The surgeon of the future will doubtless replace diseased kidneys and other vital organs with normal ones, but the substituted organs will be taken from human subjects,—say from the victims of accidents, or from executed criminals.

TRACING BLOOD RELATIONSHIP

The specific quality which thus pervades every tissue of an organism—so that the remotest cell of

a cat, for example, has some quality of *felineness* that distinguishes it from a cell of any other species of animal—extends its mysterious influence so comprehensively that it includes not merely every fibre of the organism but every drop of blood in an animal's body.

The proof of this has been given in a remarkable series of experiments conducted by Professor G. H. F. Nuttall, the American biologist, now of the University of Cambridge.

Professor Nuttall has developed a system of blood testing of such delicacy as quite to transcend the bounds of microscopic examination or of any chemical methods hitherto known; and in so doing has found a method of testing the relationships of different tribes of animals that seems little less than magical.

The tests show, for example, that man is more closely related to the old world monkeys than to the monkeys of the new world; our closest relatives being the chimpanzee, the gorilla, and the orang in the order named. Similarly the relationships between different members of the dog family, the cat family, and the like are traced. Thus the hyena appears to be to some extent intermediate between dog and cat tribes, but, contrary to what might be expected, it is much more closely related to the cat than to the dog. The seal and sea lion, on the other hand, are closer to the dog family than to the cats. Moreover the seals are somewhat more closely related to the weazel tribe than to the felines.

The porpoise, which might be supposed to be allied to the seal, is found instead to show close affinities

PROFESSOR G. H. F. NUTTALL

with the ox tribe, and in particular with the pigs. Indeed the porpoise may be regarded as a pig that has taken to the water and perforce become carniverous in diet. It is necessary also to record the rather unflattering observation that the blood of the porpoise shows more pronounced affinities with human blood than with that of most other animals.

The family groupings among reptiles show close blood relationship between lizards and serpents, and a slightly less close relationship between turtles and crocodiles. The reptiles are more closely related to birds than to mammals. The relationship appears to be particularly close between birds and turtles; less close between birds and crocodiles; the avian relationship with lizards and serpents being still more remote.

FROM LABORATORY TO POLICE COURT

These tests singularly confirm the conclusions of the zoölogist, based on study of the anatomical structures of the different tribes of animals; but the testimony is absolutely independent, the tests being made, as already pointed out, by means of blood alone.

Indeed the maker of the test may never have seen a specimen of the species whose rank in the organic scale he is determining. The specimens of blood that Professor Nuttall used in his classical series of experiments were collected from a multitude of sources; no fewer than seventy different persons sending specimens from different parts of the globe.

Many of the collectors were hunters, who merely dipped a piece of filter paper in the blood of a quarry

and transmitted it to the Cambridge Laboratory. There the discolored piece of paper was soaked in water to produce a clear solution of blood serum. A portion of this solution was placed in a test-tube, and this test-tube put in a rack along with scores of other specimens, each bearing only a number.

Into each test-tube a small drop of a certain liquid was placed. If the solution in the test-tube became cloudy, the experimenter was able to pronounce definitely that the blood was that of an animal of a certain tribe. It might, for example, be the blood of a tiger or a leopard or a panther or a cheetah; but it could not be the blood of a hyena or a wolf or a dog.

Again the test might be applied to a blood stain on a handkerchief or knife, or on a fragment of wood from a floor or window sill, or scraped from the surface of a boot or a coin. In this case the proof as to whether the stain was caused by human blood or by that of some animal might be the deciding testimony in a murder trial.

Here the method of procedure would be the same as before. A solution being made from the blood stain and placed in a test-tube, the trial fluid would determine whether the stain was due to human blood. If the test proved negative, other tests might determine what particular animal supplied the blood. In a case reported by Professor Uhlenroth, for example, a blood spot in the road, suspected to be of human origin, was found to be from the blood of a pig. In another case blood stains on a garment were reported as being partly human and partly due to the blood

of the sheep. In this case it was subsequently proved in court that the wearer of the garment had committed a murder, but that he had slaughtered sheep two weeks before the murder.

The importance of such a test from a medico-legal standpoint is obvious. It has been shown that the test can be applied to blood stains on the most varied materials, including wallpaper, wood, stone, coal, coke, straw, rubber, linoleum, silver and copper coins, and even shoes that had been blackened after the blood was spattered over their surface. Various implements that had figured in murder trials were supplied by Scotland Yard to the Cambridge Laboratory to discover whether the tests could be applied to blood stains of long standing. It was found that the age of the stain made no particular difference. Blood stains of twenty-eight and thirty years' standing on knives and razors responded to the test and gave unequivocal evidence of their human origin.

HOW THE TEST FLUIDS ARE DEVELOPED

A word now as to the production of the magical fluid with which such tests are operated. The fluid consists of a portion of blood serum drawn from the veins of a rabbit. The peculiar properties of the serum have been developed by repeated injections into the system of the serum of human blood or that of some other member of the animal kingdom, according to the particular type of test that is to be made.

A rabbit inoculated with human blood develops a so-called anti-human serum. Another rabbit in-

oculated with the blood serum of a cat, will develop an anti-feline serum; and so for all other tribes of animals,—including not merely mammals but birds, reptiles, and even crustaceans, such as the lobster and its allies.

The explanation of the development in the body of the rabbit of the peculiar quality of blood that gives the anti-serum its value in such tests as those outlined, is found in the fact that the blood of almost any animal has a certain quality of toxicity when injected into the veins of an animal of different species. In some cases this action may be very virulent.

For example, fifteen drops of the blood of an eel injected into the veins of a dog weighing about thirty pounds may produce death in seven or eight minutes.

In another experiment ten drops of the blood serum of an eel killed a rabbit of ordinary size in two-and-a-half minutes. The foreign blood serum appears to attack the blood corpuscles, rendering them functionless and presently dissolving them.

Curiously enough the blood corpuscles of newborn rabbits are much more resistant to foreign blood than are those of the adult rabbit. But a certain degree of resistance obtains in all animals, and this may be accentuated by introducing a very small quantity of foreign blood serum, and from time to time repeating and increasing the dose. In this way the system of the animal becomes to some extent immune to the poisonous effect of the foreign blood, through development of what for want of a better term is called an anti-serum.

The blood of a rabbit that has attained this condition may then be used in testing for the presence of the particular type of blood that was used in developing the anti-serum. For example, if human blood was the kind injected into the system of the rabbit, the rabbit's blood will now serve as a test for human blood.

MAN'S REMOTE RELATIVES

It appears, however, that the anti-serum thus developed, while its most pronounced reactions will be given with solutions of human blood, will also react in a less marked degree with the blood of other animals.

If successive drops of the anti-serum are introduced into one test-tube after another, as in the Cambridge experiments, it will be observed that in some tubes there is an immediate reaction, resulting in a white precipitate. In other tubes the reaction will set in only after some minutes; in yet others after hours; and the remaining test-tubes will remain permanently clear. It is these graded results that enable the experimenter to test the blood relationships of the different animals.

It is found, for example, that when a test is made with human anti-serum, an immediate reaction is observed only in test-tubes containing human blood. Less prompt and less marked reaction occurs in the tubes containing the blood of the man-apes; still milder reaction in the case of baboons, monkeys, and marmosets in succession; and a long delayed or altogether negative result in all other cases. It is ob-

vious how similar tests with other types of anti-sera enable the experimenter to follow out the relationships of different tribes of animals.

Professor Nuttall's experiments comprised sixteen thousand individual tests, with a total of at least 586 species—mammals, birds, reptiles, batrachian, fishes, crustaceans—coming from all parts of the globe. These experiments are in themselves highly interesting; in their implications they are nothing less than astounding.

Doubtless some hundreds of thousands of years have elapsed since the direct ancestors of men branched from a common stem with the direct ancestors of the gorilla. There has been no blending of blood in the intervening centuries. Cats have been cats and dogs dogs from geological epochs so remote that we hesitate to guess their span in terms of years. So the intimate chemical qualties that denote man or ape or cat or dog, each in contradistinction to all the others, must have been transmitted unmodified through countless thousands of generations.

It taxes credulity to believe that such intangible properties could be transmitted unmodified through the blood streams of such myriads of individuals; but the evidence of the test-tubes proves that this has been done.

What makes the marvel greater is the fact that the bodies of the animals have meantime been so modified as to develop utterly divergent species,—for example, the lion, the tiger, the puma, the leopard, and the house cat; different types of dogs, wolves, foxes, and their allies. But in each case some intangible

quality of the blood remains unchanged to prove the common origin. Blood is indeed thicker than water.

GROWING ANIMAL TISSUES OUTSIDE THE BODY

It has been observed that the remarkable fluid with which Dr. Nuttall's wizard-like tests are made is developed in the body of an animal. I wish now to tell of a series of experiments in which the process is reversed, and tissues taken from the body are made to grow in glass receptacles.

When I add that the tissues that are thus cultivated under glass have perhaps been cut from the body of a dead chicken that has hung for some days in cold storage, the reader will divine that the experiments in question are something out of the ordinary. Possibly they constitute the most remarkable of the various types of life-juggling experiments with which this chapter is concerned.

The chief innovators in the art of growing living tissues in an incubator are Drs. Alexis Carrel and Montrose T. Burrows, of the Rockfeller Institute, though Dr. Leo Loeb had earlier made tentative experiments and Dr. R. S. Harrison was the first to prove the feasibility of such investigations. Dr. Harrison (1907) worked with embryological tissues. Drs. Carrel and Burrows generalized the method in 1910. The tissues experimented with are fragments of spleen or liver or skin of the chicken or of various higher animals. Similar tests have also been made with fragments cut from various abnormal growths including malignant tumors. Indeed, tissues of almost every character may be utilized successfully.

The fragments of tissues are removed by rapid incision from the organs of animals recently killed, or the bodies of which have been kept in cold storage. The transfer of this tissue to the medium in which it is to grow must be made quickly, as exposure to the air for more than a few seconds may cause the death of the cells. The culture medium consists chiefly of blood plasma, which may be variously modified to test the influence of different chemicals on the growth of different types of cells.

The tissue in its glass receptacle is placed in an incubator, kept at body temperature, from which it may be from time to time removed for examination.

The growth of the cells may be obvious to the naked eye through the increasing size of the original fragment; and it may be more specifically observed under the microscope. In the latter case the microscope is mounted on a heated receptacle so that injury may not be done to the growing tissue by prolonged subjection to altered temperature.

It is curious to note, however, that whereas exposure to ordinary room temperature for a period of half an hour or so would destroy the tissue, it may be placed in cold storage for a good many hours, or even days, without permanent loss of vitality. Apparently freezing interrupts the chemical changes and brings about a virtual rest of the cells. Of course chemical action is not absolutely stopped, but it is so much retarded that the destructive changes that would occur at ordinary temperature in the course of a few minutes may be delayed for hours or days.

We noted that the tissues for cultivation under

glass may be cut from a dead animal, and even from one that has hung for several days in cold storage. This proves, obviously enough, that the bodily tissues do not lose their vitality immediately after the death of an individual organism. A decapitated chicken that has hung three or four days in an ice chest is unequivocally dead, according to the ordinary meaning of words. Yet various of its tissues may still be alive, as the experiments of Drs. Carrel and Burrows show; and may be not only kept alive but caused to develop new cells,—that is to say, to *grow*, as only living tissues can do.

PRACTICAL APPLICATIONS

It would be difficult to overestimate the value of this new method, as placing in the hands of the physiologist and the practical physician and surgeon, new means of testing remedies and new possibilities of progress in scientific medicine.

Within a few months of the time when the first experiments were made, Professor Von Wassermann, at Berlin, and Professor Ehrlich, in Frankfort, have announced the discovery of drugs that attack cancer cells in mice and cause the destruction of these malignant tumors. It is understood that the experiments which gave clues to the remedies that would thus have a selective action on the cancer cells were made, in part at least, with tissues grown outside the body according to the method of Drs. Carrel and Burrows.

This may be regarded as an augury of many other therapeutic discoveries. Indeed we can scarcely doubt that ultimately our knowledge of the effects of

various drugs upon different tissues of the body will be given a specific character that could hardly have been attained by any previously known method of experimentation.

Another application of the knowledge that tissues cut from excised organs may retain vitality for considerable periods, was made recently by a Paris surgeon, who restored partial sight to a blind man by excising a portion of the opaque cornea of his eye and replacing it with a piece of cornea of like size cut from an enucleated eye that had been kept for some days in a refrigerator. The operation was successful, in that the fragment of cornea took kindly to its new surroundings and grew permanently into place, retaining its transparency. It would be hazardous to fix bounds to the transplantations of tissues that will be effected by the surgeon of the future. Even now, as it appears, it is possible to relieve a condition of blindness that is very common, and which hitherto has been considered incurable.

There is one other aspect of the experiment of growing tissues outside the body which suggests possibilities even more bizarre and startling. I refer to the tests which show that the embryo of a chicken may be removed from the egg and caused, for a time at least, to continue its development in the culture medium. Similar tests were made with fragments of animal embryos. The embryos, to be sure, did not come to maturity; but the fact that they lived and grew for a time suggests astounding possibilities for the method when it is perfected.

It would seem to be within the possibilities that

the method may ultimately be so perfected that embryos of all kinds, including the human, could be grown in culture media in the incubator.

Should this expectation be fulfilled, the woman of the future may be emancipated from the primal curse that her maternal ancestors have borne since bisexual organisms were evolved. What this final feat of life-juggling might mean to humanity, I leave for the reader's imagination to suggest.

VI

THE CREATION OF SPECIES

QUESTIONS as to the origin of man are always fascinating. The broad general proposition that man is an evolutionary product and has lineage, could we trace it, extending down to the lowest forms of life, is so firmly established, thanks to Darwin and his successors, that it now seems almost axiomatic. That the mammals, with man at their head, represent an offshoot from stock that includes in their collateral channels reptiles and birds, and as a more primitive division, amphibia and fishes, is matter of elementary zoology nowadays, though it issued from the realm of heresy and controversy within the memory of people who are not yet old.

But the question as to the precise stock from which the most primitive of our vertebrate ancestors sprang has reached no such stage of accepted solution. Therefore the newest attempt to answer this question has aroused no little commotion in the biological world, and will doubtless be heard of presently in unscientific circles. The author of the new theory is Professor William Patten, of Dartmouth College. Stated in a word, his theory is that the direct ancestors of the vertebrates—the missing link between the highest type of animate beings and the lower

orders—is to be sought in a particular tribe of creatures called Arachnids, of which the spiders, scorpions, and mites are the most familiar examples. Making a very popular paraphrase, we may perhaps say that Professor Patten's theory suggests—though he of course, would not phrase it precisely this way—that man, in common with his vertebrate relatives, is a modified spider or scorpion.

It must be explained at once that Professor Patten does not suggest that any vertebrate has been developed through modification or adaptation of the structure of any existing form of spider or scorpion. What is suggested is that at a very ancient period a form of life existed which was destined to supply the common ancestry of spiders and their allies and of all the vertebrates. These creatures, according to Professor Patten's theory, were marine arachnids, of a type known as sea scorpions. They were confessedly the most highly organized animals of their time; and Professor Patten believes that in due course their descendants were modified to form a very interesting type of creature called an ostracoderm, which in turn gave rise to the fishes or first true vertebrates. Professor Patten thinks that this theory, if demonstrated, will lead to the most radical change in the classification of the animal kingdom that has taken place since the time of the great comparative anatomists Cuvier and Lamarck. He thinks that the whole story of the evolution of the vertebrate stock, which has hitherto been veiled in mystery, should become an open book, since the material for its reading is abundant and accessible.

It may be well to recall that it was Lamarck who originated the terms vertebrate and invertebrate and called attention to the all-importance of the spinal column as a feature of animal morphology just at the beginning of the nineteenth century; and that Cuvier soon afterward divided the entire invertebrate population of the globe into articulates, mollusks, and radiates, familiar examples of these divisions being insects, the oyster, and the star fish. This classification was accepted for the better part of a century, but in recent years students of the great company of invertebrates have thought further subdivisions desirable, and it is now recognized that animate beings have developed along at least seven or eight divergent lines, though all springing from the same primordial root.

It is nowadays considered a broader view to think of the great major groups of animals—let us say coelenterates, echinoderms, worms, arthropode, mollusks, brachiopods, and vertebrates—as being each more or less perfect of its kind, rather to be likened to the various branches of a spreading tree than to be rated in serial order one above the other.

In this view the distinction between Vertebrates and Invertebrates loses a good deal of its early significance. The total vertebrate population of the globe is after all a mere handful contrasted with the myriads of individuals, and scores of thousands of species, of invertebrate forms. Nevertheless it is natural from a human standpoint to regard the vertebrates as the highest and finest branch of the tree; though it is comprehensible that from the standpoint,

let us say, of the ant the question might seem debatable. Be that as it may, it is assuredly not unnatural that man should be supremely interested in the question of his own ancestry; hence the assiduity with which zoologists have sought to ascertain what manner of creature it was from which the lowest vertebrate directly sprang. It is this question, as already intimated, which Professor Patten now thinks himself able to answer.

THE TRUE MISSING LINK

The primitive ostracoderms which Professor Patten now brings into the limelight, so to speak, had been known for a good many years as obscure fossils found in strata of the so-called Silurian period; but no one had ascribed great importance to them until it occurred to Professor Patten that the location of the remains of these creatures in strata just above the fossil sea scorpions and just below the earliest fishes, taken with the peculiar formation of the ostracoderms themselves, suggested that the sea scorpions, the ostracoderms, and the fishes, "represent three successive stages in the evolution of the animal kingdom, just as in the later periods the fishes, the amphibia, and the mammals represent successive stages in the evolution of the vertebrates."

This is equivalent to suggesting that the ostracoderms are the true link between vertebrates and invertebrates, which the classifiers had hitherto so vainly sought.

In attempting to satisfy himself as to the validity of his theory, Professor Patten has searched far and

wide for fossil specimens that would reveal details as to the structure of the ostracoderms. His visits to the best zoological collections of Europe gave a good deal of information but left much to be desired. He then began the systematic searching of certain strata of fossil-bearing rocks at the Bay of Chaleur in Canada. Here fragments of fossils were found on the beach at low tide, or could be obtained by splitting open disk-shaped nodules that had washed from the adjacent cliff. To secure perfect specimens it was necessary to make excavations in the face of the cliff itself. For four successive summers this work was carried on, many tons of rock being dug out and split open, before a rich fossil bed was discovered.

The exploration of this bed proved hazardous as masses of rock fell from time to time from the crumbling cliffs. But the excavation was continued, and the bed was found literally to teem with the remains of a particular species of ostracoderm (*Eothriolepis Canadensis*) in a state of preservation more complete and instructive, Professor Patten thinks, than that of any other fossil found heretofore. In a recent article in "The Popular Science Monthly," Professor Patten gives a vivid description of the finding of this fossil bed, and a most interesting account of the probable way in which it was formed, way back in a romote geological era.

"The bed had apparently formed the bottom of a shallow brackish water-pool in which fern-like water plants had been growing, and where many millions of years ago, with the rise and fall of the tides, these specimens had been trapped, together with other

species of ostracoderms and several kinds of true fishes.

"The soft mud on the bottom of the pool was now turned into a fine-grained, sandy limestone, and in it the fossilized animals were preserved in the very attitudes they had assumed when they ceased to struggle out of the enclosure. One in its death agony, had plunged into the mud with sufficient force to remain there, head down, in a vertical position. Others were arranged in horizontal series, uniformly headed in a northeast direction. Their heads were turned against a gentle current of water, as was shown by the fact that the tops of all the ferns were pointed in nearly the opposite direction."

Some of these specimens were so well preserved that the shape of the body and many details of its external surface could readily be observed. Moreover, when the specimens had been transported to the laboratory and there laboriously cut into sections with the diamond saw, and the sections polished and varnished, the arrangement of the internal organs was also revealed. And it is the study of these specimens which leads Professor Patten now to declare with much confidence that the ostracoderms were neither vertebrates nor invertebrates, but a class intermediate between the two: "In fact, the real missing links in the animal kingdom. The posterior part of the body was membraneous and decidedly fish-like in shape; but the contour of the whole animal, especially the head, the natural appendages, the eyes, and the mode of locomotion, were more like those of the marine scorpions. The

gill or atrial chamber, and the structure of the dermal skeleton were intermediate in character. But the most important features of all were the long-sought-for mouth parts or jaws. They were paired, consisting of four separate jaws, which in chewing or biting moved to and from a median line, like the jaws of all known arthropods. They were not unpaired arches moving forward and backward as they had in all true vertebrates."

The character of the mouth, then, allies the ostracoderm to the tribe of spiders and scorpions rather than to the vertebrates. But it chances that studies of the embryos of vertebrates, say of a frog, show that at its earlier stages of development each individual vertebrate passes through a stage in which its jaws have the character of the jaws of the ostracoderm. Inasmuch as it is an accepted thesis of biology that the embryo of a higher organism reproduces in epitome the history of racial evolution, this seems clearly to imply that the developing vertebrates in point of fact passed through a stage in which their mouths were like the mouth of the ostracoderm.

There are many other points of the embryological story which are equally suggestive, but which have explicit meaning only for the trained anatomist. Suffice it that Professor Patten is convinced that the facts of embryology go hand in hand with his studies of the fossils in giving support to his theory of the arachnid origin of the vertebrates. Needless to say, the theory will not be accepted without controversy. But pending further investigation, we are justified

PROFESSOR WILLIAM PATTEN WORKING WITH FOSSIL OSTRACODERMS

in looking upon the ostracoderm as a probable direct ancestor of man, and by the same token we must acknowledge a possible racial affinity with the great tribe of spiders and scorpions which the instinctive attitude of mind of most people toward those creatures would not have suggested.

So much for the popular point of view. In conclusion, as showing the technical importance of the work, let me quote a brief paragraph or two from a letter which gives a glimpse of the method of the worker and the importance of the problem attacked. "The work through which the theory has been developed," says Professor Patten, "covers a period of about twenty-five years, and consists of many special investigations, involving elaborate details in technique and subject-matter, in such widely separated fields as comparative anatomy, embryology, physiology, and palaeontology, of both vertebrates and invertebrates. The problem as a whole is the most important one—to the biologist—since the general acceptance of the doctrine of evolution. It has been tried in many different ways—by the most distinguished morphologists of England, Germany, France, and Russia. If this solution of it is even approximately correct—it is already conceded to be 'truly monumental work,' 'the best solution available,' 'the most comprehensive one that has been offered'—it will revolutionize the science of comparative anatomy and embryology, and lay the foundation for a new philosophy of creative evolution."

Let me add that, whatever the outcome, the solu-

tion of the problem is a new and highly interesting one. The originality, breadth of treatment, accuracy, and technical skill of the author are not questioned. Whether in the end his theory be accepted or rejected, it will remain a creditable product of American scholarship.

EVOLUTION THROUGH NATURAL SELECTION

Such studies as this show that speculation as to the precise line of man's early ancestry has been by no means idle. Yet it is doubtless true that the main body of biological workers of the present generation are chiefly concerned not with the origin of the main stem itself, but with the forces that have been at work in modifying the descendants. And in very recent years a vast amount of information has been gathered regarding the influences through which vegetable and animal organisms may be modified. Already important applications of this knowledge are being made, and it is probable that vastly more important ones will be made in the not distant future, which will vitally influence the well-being of the human race.

To understand the bearings of the new knowledge we must first very briefly review the essential ideas connected with the Darwinian conception of the origin of species.

The essence of the Darwinian doctrine is the idea that evolution has taken place through the preservation of what Darwin spoke of as favored races. The struggle for existence is everywhere hard, and only a very small proportion of creatures born into the

world can attain maturity and propagate their kind. A plant may produce a hundred thousand seeds. If all came to maturity and reproduced their kind in like measure, every square inch of the earth's surface would be covered with the descendants of this single plant in a very few years. Similarly a codfish may lay a million eggs. If all hatched and the offspring propagated normally, the mass of codfish produced in a century would surround the earth in a solid body, reaching out in every direction well toward the orbit of the moon. The progeny of one fly in a single summer, if it lived and propagated normally, would amount to several million bushels of flies. The progeny of a single human pair in the time since the discovery of America might readily enough give us our population of a hundred million individuals.

So it is obvious that the actual rate of increase of any given plant or animal or human family can be but a very trifling fraction of the normal or nominal increase; and the reason is simply that the conditions of life are more or less unfavorable for every race, chiefly owing to the competition of the members of the same or of other races. This is what is meant by the phrase "struggle for existence" as applied by the evolutionist. The phrase applies equally well to the lowest plant and to the highest animal.

In the case of plant and animal alike the individual that differs slightly from its fellows in some favorable direction is obviously the one likely to be preserved. Such an individual will tend to transmit its inherent peculiarities, and its descendants will constitute a favored race.

This process of the weeding out of the unfit, through survival and dominance of the relatively fit, Darwin spoke of as natural selection. The doctrine presupposes that individuals of a species do vary from one another, but Darwin made no attempt to explain such varieties. He recognized of course that all variations must be due to the operation of natural laws; but he recognized also that we are at present in ignorance as to the exact character of these laws. So he confessedly begged the question by speaking of the divergence between different mmbers of the same species as constituting "spontaneous" variation.

That such variations occur is matter of every-day observation. In point of fact no two individuals of any species are absolutely identical, so that variation may be said to be the undeviating rule rather than the exception. As any given variation must, obviously, be in some degree either favorable or unfavorable to the individual, it would appear as if the materials for the operation of natural selection are ever present, and as if each species might be supposed to be in a state of slow but constant fluctuation. The accumulation of slight variations, passed on from one generation to another, was supposed to account, granted time enough, for the development of the divergent forms of life that are observed to people the world,—from the single-celled protozoon to man.

THE NEW THEORY OF MUTATION

Let it be said once for all that this Darwinian idea of the origin of species through natural selection,

stands to-day unchallenged in its broad essentials. It is the one only explanation of the development of races that adequately explains the known facts. It is essential that this should be stated clearly, because we hear a great deal nowadays of sundry schools of evolutionists who appear to be disputing the Darwinian principles. It is therefore not superfluous to assure the general reader that, in so far as these various disputants speak with any measure of authority, their disputes concern details as to the evolutionary processes, and do not put in jeopardy the fundamental Darwinian conceptions.

The name of Darwin stands to-day as it has stood for half a century, supreme and unchallenged, as that of the champion and expounder of the most important biological doctrine that has ever been put forward in the history of science.

There are certain very important details, however, regarding which the recent observers have explained and interpreted the Darwinian doctrine. The most striking of these has led to the introduction of the theory of so-called evolution by mutation.

The import of this theory is simply that the "spontaneous" variations through which favored races are produced may be of a much more pronounced character than had generally been assumed. The immediate followers of Darwin had generally thought of the variations between individuals of a species as being very slight in degree, so that the cumulative effect of many slight variations, extending over multitudes of generations, would be necessary to produce a radically new type of animal or

plant. If the divergent forms that now exist—insects, fish, reptiles, birds, mammals—have indeed been produced from the same lowly common ancestors by such slow processes of variation, the time required for the evolution of existing races must obviously be enormously long.

Some students of the earth's rocky structure have doubted that the actual lapse of geological ages is sufficient to justify the theory of evolution through the cumulative effect of slight variations. Geological time is assuredly long; but is it long enough? The biologists said that it must be; many geologists denied that it could be.

A possible solution of the controversy has recently been found in a modification of the Darwinian theory suggested by Professor Hugo de Vries, of Amsterdam. The studies of this far-sighted experimental botanist convinced him that the "spontaneous variations" on which evolution works are often much more pronounced deviations from "type" than had usually been assumed. From seed-pods of the same plant may come individual plants that differ among themselves not only slightly, but sometimes very radically. In exceptional cases, as Professor de Vries discovered, the deviation may be so marked that one of the plants may fairly be regarded as constituting a new race or "elementary" species. Such a departure from type, developed suddenly in a single generation, Professor de Vries spoke of as "mutation."

The plant which furnished the most striking evidence for the new mutation theory was found by Professor de Vries near Amsterdam. It is a species

known as the Evening Primrose, a plant familiar as a roadside weed in the United States, where it is indigenous. The specimens growing in the fields near Amsterdam are the descendants of plants originally brought from America.

It would appear that the evening primrose has a peculiar and characteristic propensity to vary in type; and it is probable that this propensity to vary has been accentuated by some obscure influence of changed nutritional conditions due to the European soil. In any event, Professor de Vries observed that plants seemingly the offspring of the same parent plant, differ very widely among themselves.

Gathering seed and experimenting in his botanical garden at Amsterdam, De Vries was able to develop, in the course of successive generations, no fewer than twelve races of evening primrose from a common stock.

The experiments involved the planting of many thousands of seeds with elaborate precautions against cross-fertilization. But the results were unequivocal. A dwarf form of evening primrose might be the offspring of a giant form; and the dwarf, sprung into being in a single generation, would breed true.

In other words, a new race, differing so widely from the old that it might justly be termed a new species, was observed to develop in a single generation. Thus the necessity for assuming that evolution has proceeded only through the natural selection of *minute* variations, was done away with. It was made clear that Nature might supply by mutation widely divergent types through which natural selection

could operate to produce new species. Thus the transformation from, let us say, a tall to a dwarf species of evening primrose, instead of requiring centuries might take place in a single year.

Although the evening primrose is the only plant in which such marked mutations have been observed, it is reasonable to suppose that other plants, and animals as well, may show similar tendency to marked variations under exceptional circumstances (for example, through changed environment). So the evolutionary process might go on with incomparably greater rapidity than had been supposed possible without involving any force more mysterious than the accepted Darwinian principle of "natural selection" and the survival of the fittest. Thus any dispute about the adequacy of geological time was shown to be unnecessary.

THE PRODUCTION OF MUTANTS

It must be observed that the sudden variations which produced Professor de Vries' new species of evening primrose may be spoken of as "spontaneous" in the original Darwinian use of the word. No one can explain, except in the most general terms, why certain individual plants depart from their hereditary type in so striking a manner. In general terms, however, it might be said that the mutation is doubtless due to some changes of nutrition. In recent years a large number of experimenters have been at work endeavoring to ascertain what manner of influence may be instrumental in causing such mutations as are observed to occur.

A certain measure of success has attended these experiments. For example, Dr. D. T. MacDougal has treated the ovaries of the evening primrose flower with various chemicals, and the seeds from flowers thus treated sometimes produce plants entirely different from the mother plant. Professor C. S. Gager has gained corresponding results by treating the pollen of plants with radium. Professor T. H. Morgan has similarly subjected the eggs of a certain fly called Drosophila to the influence of radium, and has produced individuals differing in some striking respects from their parents. One, for example, had very short wings, and it was found that these short-winged mutants bred true for successive generations.

Professor Jacques Loeb, in association with Mr. F. W. Bancroft, has experimented with the same species of fly, to see what effect might be produced by subjecting the insect to high temperature. The flies were bred in a thermostat, the temperature of which was kept constant within one degree of 30.5 degrees Centigrade. Under these circumstances, in the fifth generation a number of dark flies appeared, and it was found that this dark variety constituted a permanent race. Subsequent experiments, however, showed that the influence of temperature did not necessarily produce dark mutants. Experiments with radium were also somewhat indeterminate, although divergent forms—dark races, pink-eyed, white-eyed, and short-winged forms—were sometimes produced.

Professor W. L. Tower, in experiments with bee-

tles, has produced equally striking and rather more definite results. By subjecting the eggs of the beetles to different degrees of temperature and moisture from those in which they usually live, he was able to produce certain color mutations at desire.

These and similar experiments made it seem probable that new races of plants and animals have appeared through mutations in the past and are likely to appear at any time when through voluntary or involuntary migration a species of animal or plant is brought under the influence of a changed environment. But the development of the new race, though we may suppose it to be much more rapid than had hitherto been imagined, need not depend upon any principles divergent from those which Darwin originally expounded.

THE WORK OF LUTHER BURBANK

Doubtless the greatest practical demonstrator of the truth of the Darwinian theories of heredity is Mr. Luther Burbank, the famous developer of new varieties of plants. Mr. Burbank's work, which began when he was a young man in New England, and which has been carried on for the past forty odd years at Santa Rosa, California, has included practical experiments with hundreds of species of plants, the number of his carefully gauged and recorded experiments running into the hundreds of thousands.

Every one has heard more or less of the results achieved by this wizard among plant experimentors. His first important results were obtained with the potato, which he raised from the seed, thereby pro-

ducing a new variety of exceptional size and quality. The potato, as every one knows, is ordinarily reared from the tuber and it has almost lost the habit of producing seeds. Thus it fails to benefit by the cross fertilization that has such an invigorating effect upon most species of plants. Occasionally, however, the potato does produce a seed-ball, and it was by experimenting with such an exceptional find that Mr. Burbank produced his first new variety of vegetable and, incidentally, discovered his true bent.

In California Mr. Burbank has gone from one achievement to another, until the list of new flowers, vegetables, and fruits that he has developed extends to bewildering lengths. By crossing the Japanese plum with an American plum he produced the fine fruit that has revolutionized the prune industry in California. By crossing the plum and apricot he produced a fruit that he calls the "plumcot," which, if discovered in a state of nature, would be regarded as a new species; a fruit that combines the qualities of both of its progenitors. He has produced walnuts with shells so thin that a bird can easily penetrate them, and then from these has developed others with slightly thicker shells to remedy the defect. He has stimulated the growth of trees until he can show walnuts that bear within eighteen months from the time the nut is planted,—whereas ordinarily the tree required eighteen or twenty years to attain maturity.

Working with flowers, Mr. Burbank has given a sweet scent to the calla lily; has produced three altogether different poppies from a single parent stock; and, on the other hand, has combined the qualities of

three species of daisies to produce the new "Shasta" daisy which, judged by its form and color, would itself rank as an individual species.

Experimenting in another direction with fruits, he has produced plums that have no stones, and cherries for canning purposes that leave the stone on the tree when picked. He has been able to breed the thorns off the raspberry and blackberry bushes and to produce a white blackberry which was originally as great a novelty as a white blackbird, but which now is no longer rare.

Yet another achievement has consisted in developing a race of spineless cactus, which now breeds true and which is supplying the deserts with a new forage food.

All this and much more in kind Mr. Burbank has accomplished through application of the great principle of selection. "The begining and the end in plant breeding," he says, "is selection. First the selection of varieties as nature presents them to us; second, improvement of these varieties, and combinations to produce still other varieties, and then—still further selection."

Here, then, is the Darwinian principle applied with the aid of human intelligence to accomplish rapidly the changes that Nature could accomplish only in long periods of time. But in making the selections, Mr. Burbank is aided by powers of observation and by intuitions that place him quite in a class by himself. Mr. Burbank has said that Darwin was one of the best observers that ever lived. The same remark might be applied to Mr. Burbank himself. He is able

to note differences between various specimens of a plant that to the ordinary observer are unrecognizable and his original intuition, aided by long years of experience, enables him to select the one specimen among thousands that will lead him straight to the mark. So he succeeds where a less skillful experimentor might fail utterly.

Then, too, he has those other essential characteristics of the successful man, untiring energy and unbounded patience. Where another experimentor tries, for example, to effect the hybridization of two species and after three or four failures give up the effort, Mr. Burbank goes on with scores or hundreds of experiments until at last he achieves success. It is thus that he has been able to break down the barriers that seem to lie between different species and to give practical demonstration to the fact, which philosophical biologists have more and more clearly recognized in theory, that the word "species" is a term invented for human convenience rather than the expression of anything fundamental in nature.

But from first to last, let it be repeated, Mr. Burbank operates by selecting what nature has supplied. Aside from the bringing out of latent qualities through cross fertilization, he makes no claim to create characteristics, or to do anything beyond bringing into the foreground propensities that have been subordinated in a given plant. At most, he unites old traits into new combinations. By shrewd prevision and intelligent management he virtually creates new species in a few years; but his entire method of work is a practical exemplification of the methods through

which species have slowly been developed in the state of nature in the long periods of the past.

Mr. Burbank has been known to speak of "taming a wild plant, and training it so that it will break into new habits and forms." In such "training" he depends in part upon the influence of changed environment and very largely upon introducing new tendencies by cross fertilization. In the practical combining or fixing of traits, adjusted now to the artificial environment of man's creation, Mr. Burbank has had wider experience, doubtless, than any other experimentor. The net result of all his observations is to fortify his conviction that Darwin's conception of heredity was comprehensive and profound. And with this conclusion authoritative biologists everywhere are in full accord.

THE NEW THEORY OF MENDELISM

There is, however, a new application of the laws of heredity as applied to the mingling of divergent races, with which Darwin was not familiar, and which many biologists of to-day believe to be of supreme importance. This is the theory which, after the name of its promulgator, is known as Mendelism.

Mendelism: the word is one to remember. No other word is used quite so frequently by the biological workers of our time. It is a word that promises to vie with the word Darwinism in its bearing on the doctrines of heredity as applied to the animal world, including man himself. It has not yet had time to make its way into the popular vocabulary, but it promises soon to attain that distinction.

Gregor Mendel, the Austro-Silesian priest, lived the life of an obscure abbot in the cloister of Brünn, and died in 1884, at the age of sixty-one, absolutely unknown to fame. To-day his name is mentioned almost reverentially by a host of biologists all over the world, and it is felt by many that his niche in the temple of fame must be side by side with that of Charles Darwin. One of the most philosophical biologists of our time has said that he dates the birth of scientific biology from the year 1863; in which Mendel published in an obscure periodical the first account of his researches,—an account to which no one paid the slightest attention at the time or for more than a quarter of a century thereafter.

The entire history of science shows no other case quite comparable to this. Posterity frequently enough juggles with reputations and refuses to remember men who achieved wide reputation while they lived. But I recall no other case in which a man who lived and died unknown to fame, seemingly without making an impress on the thought of his generation, has been glorified by the immediately succeeding generation. So the case of the Abbot of Brünn has peculiar significance even for that part of the world which takes no interest in affairs scientific.

What, then, was the scientific achievement which gave this obscure priest such astonishing measure of posthumous fame? The answer will doubtless surprise the reader who chances not to have heard the story. The achievement, which by common consent of present-day biologists was really a mo-

mentous one, consisted in the main of a series of careful observations on the cultivation of ordinary eating peas in the garden of the cloister of Brünn.

It will readily be understood, after what has been said, that Mendel's observations in regard to his peas were something quite out of the ordinary. His results were indeed extraordinary to a degree. Yet like many extraordinary things they had the merit of great simplicity. The essential element of their success depended on keen observation and the capacity to make painstaking experiments, and to note the results of these experiments with accuracy and impartiality.

There was nothing in the experiments themselves that may not readily be duplicated by any one who has a small garden plot and is willing to devote a certain amount of time to the cultivation of peas.

Mendel's crucial experiments were based on the observation that different varieties of the garden pea show different qualities of vine and flower and seed-pod and seed that may be grouped or contrasted in antagonistic pairs. For example, the vines may be tall or dwarfed. The flowers may be purple or white. The pods may be smooth or hairy. The peas themselves may be smooth or wrinkled in contour, and green or yellow in color. These divergent qualities may be variously intermingled. That is to say, white flowers, for example, are not confined to either a tall or dwarfed vine; and the same is true of each of the other qualities. But a given variety of pea, once fixed as such, would show a certain combination of qualities. One variety, for example, would have a

high vine, with white flowers, smooth pods, and wrinkled yellow peas. Another variety would present some other combination of these various qualities. Mendel came to think of the various qualities as "unit characters," susceptible of being transmitted unchanged from parent to offspring. And he presently discovered some very curious facts about the manner of their transmission. He found that opposing characters—say tallness versus dwarfness—always act in the same way toward each other in inheritance.

If you cross-fertilize tall-vined and short-vined peas, for example, the hybrids of the first generation will all be tall. In Mendel's phrase, tallness is a "dominant" quality and shortness a "recessive" quality. But if the tall hybrids are now self-fertilized, as is normal with the pea, their offspring will be partly tall and partly short,—in proportion of three of the former to one of the latter on the average. And in the next generation, the offspring of this short vine will all be short; the offspring of one of the tall vines will all be tall; and the offspring of the other two tall vines will be partly tall and partly short in the proportion of three to one.

This formula will be repeated over and over in successive generations. No matter how often the experiment is repeated, the results are always the same: in the first filial generation all the offspring show the "dominant" trait, the "recessive" trait being repressed but not organically obliterated. In the second filial generation, we have one pure dominant, like the tall ancestor, one pure recessive, like

the short ancestor, and two that are mixed dominants, like their parents.

What holds for tallness and shortness holds also for each opposing pair of unit characters. Yellow seeds, for example, are dominant to green seeds; all hybrids of the first generation show yellow seeds; but of their offspring, one in four will show the recessive trait of greenness of seed, and will breed true to that trait generation after generation, quite as if there had been no strain of yellow seeds in its ancestry.

Add that the different pairs of unit characters hold their respective qualities of dominance or of recessiveness regardless of association with other characters, and we see that the manifestations of Mendelian heredity may be exceedingly diversified, yet that a clear understanding of "Mendel's Law" as just outlined may make their interpretation clear where without this knowledge for a guide they might seem exceedingly mystifying. Professor R. G. Punnett, of Cambridge University, gives a simple but effective illustration of the way in which a knowledge of Mendel's law might aid a practical breeder. He supposes the case of a gardener who has two varieties of plant each possessing a desirable character and who wishes to combine these characters in a third form:

"He may, for example, possess tall green-seeded and dwarf yellow-seeded peas, and may wish to raise a strain of green dwarfs. He makes his cross—and nothing but tall yellows result. At first sight he would appear to be further than ever from his end, for the hybrids differ more from the plant at which

he is aiming than did either of the original parents. Nevertheless, if he sow the seeds of these hybrids he may look forward with confidence to the appearance of the dwarf green. And owing to the recessive nature of both greenness and dwarfness, he can be certain for further generations the dwarf greens thus produced will come true to type. The green dwarfs are all fixed as soon as they appear, and will throw neither talls nor yellows. The less the hybrid resembles the form at which the breeder aims, the more likely is that form to breed true when it appears in the next generation."

PRACTICAL APPLICATION OF MENDEL'S LAW

Mendel's experiments and discoveries were made as early as 1863. But no one knew of his work until the rediscovery of the essential facts was made by Professor Hugo de Vries of Amsterdam about the year 1900. Professor de Vries may be said to have discovered Mendel, sixteen years after the abbot's death. Largely through the championship of the famous Amsterdam botanist, the new theory of heredity, which came to be known as Mendelism, made its way rapidly.

A host of biologists—prominent among whom in this country were Professor Jacques Loeb, now of the Rockefeller Institute, and Professor Castle of Harvard—undertook experiments that are calculated to test the new theories of heredity from many angles, and a great variety of corroborative evidence was soon in hand. It is essential that any one who would understand the bearing of the laws of hered-

ity on the breeding of a better human race should understand the essentials of what may be called the Mendelian formula. An illustration drawn from the animal world will present this perhaps more vividly than the case of the peas. If a black guinea pig of a pure black strain is mated with a white guinea pig, as in Professor Castle's experiment, all the offspring will be black. This shows that black and white, as applied to the hair of the guinea pig, are unit characters, and that the black color is dominant. But if these black guinea pigs of the second generation are allowed to inter-breed, three out of four of the offspring will be black, and the fourth will be pure white. Further breeding experiments will show that of the three black guinea pigs of this third generation, one is pure black, and will have offspring only of its own color; whereas the other two are "mixed dominants," and will have one in four of their progeny pure white.

If we were to label the four guinea pigs of the third generation A, B, C, and D (A, B, and C, being black, and D white) we shall state the Mendelian formula in its simplest aspect if we say that A is a pure dominant, and will have nothing but black descendants; and that D is a pure recessive and will have nothing but white descendants; whereas B and C are mixed dominants and will have descendants that will duplicate the A, B, C, and D formula over and over.

A clear understanding of this simple formula gives an explanation of many observed facts of heredity that were formerly mysterious. For example, Professor Punnett was able to explain anomalies in the

breeding of the barnyard fowl that had been very puzzling. In particular he explained certain peculiarities of the Andalusian breed, which is sometimes black, sometimes white with black splotches, and sometimes slate blue. Professor Punnett showed that the blue variety, which is the one prized by breeders, is in reality due to the crossing of the black variety with the white, whiteness acting as a recessive character which is bound to reappear in the offspring of the blue fowl. And in point of fact, when the blues are interbred, one quarter of the offspring are black and one quarter are white, just as the Mendelian formula requires. So the only sure way to secure a full clutch of blue fowl is to breed fowls that are not blue.

Another interesting study in Mendelian heredity, conducted at Cambridge by Professor T. B. Wood, has to do with sheep. By application of Mendelian principles, it has been found possible to cross a horned and a hornless variety of a race of sheep, in such a way as to do away with the horns and yet retain the qualities of the horned ancestor. Thus crossing a black-faced Suffolk ram with a white-faced ewe of the horned Dorset breed produces animals with speckled faces, of which the males are horned and the ewes hornless. But the succeeding generation produces individuals combining the white face of the Dorset with the hornless face of the Suffolk; and a permanent breed is established in this expeditious manner.

Doubtless the most important economic application of the Mendelian experiment that has yet been made, however, has been effected by Professor R. F. Biffin,

also of Cambridge University. Professor Biffin's experiments have had to do with the different races of wheat. England, in common with other countries, has suffered tremendously from the pest known as rust. This is a fungus growth, which attacks the stem of the wheat plant and saps its vitality. It has been estimated that the annual loss to the wheat crops of the world from this little fungus is not less than five hundred million dollars. But no method of combatting the pest proved effective.

It has long been observed, however, that there are certain varieties of wheat that are practically immune to the attack of a given variety of rust fungus. But unfortunately this immune variety of wheat, while having a strong stalk, produces very little grain, and that of an inferior quality. On the other hand, the varieties producing the finest qualities of grain have shown peculiar susceptibility to the rust. It occurred to Professor Biffin that it might be possible to hybridize these two races, along Mendelian lines. His tests soon convinced him that susceptibility and immunity to rust are a pair of Mendelian characters, of which susceptibility is dominant. When, therefore, he hybridized a susceptible and an immune wheat plant, he produced seed from which grew plants that were all susceptible to the rust. But in the following generation appeared the expected proportion, one-fourth, of plants showing the recessive quality,—which in this case was the desired immunity. So the upshot of his experiments was that he developed in the course of a few years' experimentation a race of wheat producing a larger yield of grain of fine

quality and a stalk immune to the particular type of rust which is especially prevalent in England.

Thus the work performed half a century ago by the obscure Abbot of Brünn in the garden of his cloister may result in an annual saving to the world of half a billion dollars through the application of the laws he discovered to the breeding of a single plant. But this after all is insignificant in comparison with the benefit that must accrue when the new laws of heredity are applied to the human subject.

HEREDITY AND THE HUMAN RACE

We have seen that the new heredity deals with unit characters. Unfortunately, it is not always possible to say off-hand whether any given human trait of mind or body is a unit character. Many traits that seem simple are in reality very complex, and their laws of transmission cannot be reduced to a simple formula. It is necessary that each trait shall be subjected to scrutiny. Such investigations are being made to-day along diverse lines both in Europe and America. At the Galton Institute of Eugenics, in London, Professor Karl Pearson and his associates are studying Egyptian skulls from the Catacombs on one hand, and the hereditary tendencies of modern school children on the other. In America, Professor Charles B. Davenport, as director of the Department of Experimental Evolution of the Carnegie Institute, is gathering genealogical records that already supply important data about the transmission of a large number of both normal and diseased conditions.

Until we have much fuller information than is as

yet available, it would be folly to say that we have full data for directing the marriage of human beings. But on the other hand, it is possible to draw some very practical conclusions with regard to the subject even now. The new science which Francis Galton christened "Eugenics" is in its infancy, but its progress will be far more rapid than it could have been had not the principles of Mendelian inheritance been discovered. From the remotest times it has been matter of familiar observation that both good and bad qualities of parents are likely to be transmitted to their offspring. The familiar saying that like begets like, and various equally familiar Biblical phrases about the sins of parents, illustrate the fact that the general facts of heredity are common knowledge. But the matter assumes a novel aspect in the light of the new investigations.

It had been taken for granted that the traits of two parents tend to blend in their offspring, and that any particular quality which was prominent in an individual would presently become blended with other qualities in his descendants. But the new studies of heredity show that there are many characteristics of both body and mind that do not tend thus to become modified through blending, but which may seem altogether to disappear in any given generation, or even for successive generations, and yet re-appear with full force in a remote descendant. In the words of Professor Charles B. Davenport, "After a score of generations the given characteristic may still appear unaffected by the repeated unions of foreign germ plasm."

Being interpreted, this means that each individual bears within his system and may transmit to his descendants a multitude of characteristics that he gives no evidence of having, and of which he is quite unconscious. This seems paradoxical, but it is matter of demonstration as regards a great variety of traits. A simple illustration drawn from a familiar physical characteristic will illustrate the point. Let us take the matter of the color of eyes. It appears that if a person of a racial or family strain having dark brown or black eyes marries a person with blue eyes, the offspring of the first generation will all have dark eyes. But these dark-eyed individuals, intermarrying, may have a certain proportion of blue-eyed offspring. Thus the tendency to blue eyes was a latent characteristic in the dark-eyed individuals of the second generation, though there was nothing to indicate this that even the most searching examination of their eyes by an expert would have revealed.

Following Mendel, the student of heredity, noting the fact that when black eyes are mated with blue eyes the progeny all have black eyes, names the black-eyed condition as "dominant" or positive and the blue-eyed condition as "recessive," or negative. The essential characteristic of the dominant trait, it will be recalled, is that it seems to override and obliterate the antagonistic recessive trait in a given generation. But the all-important quality of the recessive trait is its capacity to lie dormant and altogether indistinguishable in a generation, or often in successive generations, and yet ultimately to reappear seemingly quite unaffected by its long sup-

pression. Once it does re-appear, however, it "breeds true." Blue eyes mated with blue eyes, for example, always produce blue eyes.

The principles revealed in this matter of the heredity vagaries of eye-color are of supreme importance. Not that eye-color in itself particularly matters; but there are various bodily and mental characteristics of vast significance that follow the same laws of heredity. Such traits, even though complex, seem often to act in inheritance as "unit characters." If the character is of a positive nature (for example, bodily strength or vitality), it acts as a "dominant" in heredity; if negative (that is to say, due to the lack of something) it acts as a "recessive" trait. Thus eyes are dark when the iris has a certain layer of pigment; and dark eyes, as we saw, are dominant. Contrariwise, eyes are blue when they lack this layer of pigment, and blue eyes are recessive in the scheme of heredity. Similarly many diseases seem to be due to a lack of something; insanity to a lack of nervous stability; consumption to a lack of resistance to the tubercle bacillus, etc.

So we find that insanity and the tendency to consumption act as recessive traits in inheritance. The practical bearing of this on the most vital of all human actions—the choice of a marriage partner—may be made clear by a few specific illustrations, chiefly drawn from Professor Davenport's records.

HEREDITY AND EUGENICS

There are, it appears, various forms of physical disease that may disappear in one generation and

reappear in another just as does the blue eye pigment or the white coat of the guinea pig. Thus, atrophy of the optic nerve, which leads to total and incurable blindness, may run through a family strain, appearing in one generation and disappearing in the next. So a person who has no eye defect, but who belongs to a family having this defect, may transmit the tendency; and the blindness of his children may with full propriety be ascribed to heredity notwithstanding the fact that both parents had normal eyes. The same thing is true of various other eye defects, including a very distressing anomaly known as coloboma, marked by a defect of the iris and an open suture running right through the ball of the eye from the pupil to the optic nerve.

Professor Davenport gives charts showing pedigrees of families having this painful malformation of the eye. One such chart shows that a man having the defect married a normal woman, and of their two children the boy had the defect and the girl was normal. The boy married a normal woman and their only son inherited the eye defect. The daughter, whose eyes were normal, married a normal man; of their offspring, seven in number, three sons had the defect, and one son and the three daughters were normal. Another chart shows the defect appearing in a second and fifth generation, having skipped two full generations. But in this case, the marriage of cousins, introducing the defective strain from both sides, and as it were, doubling its influence, probably accounts for the reappearance of the malady in the great-grandchildren of the afflicted person.

Some of the eye diseases show a curious tendency to what is called crossed heredity; that is to say, the defect is transmitted from father to daughter, or from mother to son. Thus, color blind men do not have color blind sons, and as a rule their daughters are also normal. But these normal daughters, married to men of normal stock, have color blind sons. Of course color blindness is not a defect of such seriousness that the danger of transmitting it need be taken greatly into account in the choice of a marriage partner. But the opposite is true of a good many eye defects, including atrophy of the optic nerve and the anomaly of the iris already mentioned. Certainly no one is justified in producing offspring having a strong liability to become totally blind in early life.

The studies of these cases have proceeded so far that Professor Davenport is able to lay down some pretty definite rules that are of the utmost interest and importance. As to the dangers of heredity in a family any member of which is known to have been afflicted with the eye defect called coloboma, the rule is this: "No female with the coloboma defect should have children, since *all* sons will be defective in the structure of the pupil. For males with the defect the danger in marriage is also great, for either all or half of the sons of such a father, although married to a woman from a normal strain, will be defective, but the daughters will not be defective in this respect unless the wife belongs to a strain with this defect."

For families having the tendency to atrophy of the optic nerve the rule given is this: "a normal son of

an abnormal male may marry quite outside the family with impunity, but a normal daughter may transmit the defect to her sons. But such a woman may marry with impunity if all of her brothers are without defect and there are more than two of them. A defective male should abstain from having children, for some of his sons, at least, will probably be defective."

The principle that a person belonging to a family in which any conspicuous physical infirmity is hereditary should religiously avoid marrying into another family having the same defect is one that cannot be too forcibly insisted on. Indeed, with regard to a large number of defects this might be said to be the crux of the entire matter. A good illustration is found in the infirmity of congenital deafness. It would appear that the congenital defect that produces deaf-mutism acts as a recessive trait, and thus it may come to pass that a deaf mute married to a normal person has normal children; normality showing the same dominance here that is shown by blackness in the case of the guinea pig and dark eyes as against blue eyes.

But if, on the other hand, both parents are congenitally deaf, it was found by Fay that 26 per cent. of the offspring are deaf. When the partners belong to the same deaf mute strain—that is to say are related—the percentage of marriage yielding deaf mute offspring rises to 45, and the proportion of deaf offspring to 30 per cent. Moreover the closer the relationship of the parents the larger the proportion of deaf children. Among the cases investigat-

ed, when the parents were first or second cousins, the proportion of deaf offspring was 34.6 per cent.; and in one case in which the marriage partners were nephew and aunt, 75 per cent. of the children were deaf.

Of similar import are the facts regarding the inheritance of the condition that leads to mental overthrow. Of course insanity as such is not heritable, but the instability of the nervous system that makes one liable to mental overthrow is very pronouncedly heritable. Doctors Cannon and Rosanoff have made careful investigations of the families of patients at the King's Park State Hospital for the Insane. Omitting a certain class of "organic" cases, they found in all the cases recorded that when both parents had any form of insanity all of the children sooner or later became insane. If one parent is insane and the other normal but of insane stock, half of the children tend to become insane. What is still more significant, perhaps, from our present standpoint is the fact that when both parents, though themselves normal, belong to an insane stock, about one fourth of the children becomes insane. Dr. H. H. Goddard in his studies of the defective children at Vineland finds similar facts regarding the heredity of the feeble minded.

These are facts of the utmost practical importance. Few other afflictions are more lamentable than mental overthrow, and no rightminded person could contemplate with composure the thought of producing offspring foredoomed to become insane. So no person in whose family there is a strain of insanity, near or remote, should contemplate matrimony with-

out giving these facts close consideration. The hopeful feature of the matter is that the person even of bad heredity may marry with relative impunity if he is quite certain that the marriage partner selected is of altogether normal stock. The great difficulty is to ascertain the facts. It is not enough to make sure of individual normality; the parents and grandparents of the individual, and if possible the remoter ancestors must be considered; and it is desirable also to investigate the collateral strains as evidenced by uncles and aunts and cousins. Such an investigation would often prove difficult. But when we reflect on the care with which breeders of animals trace and guard the pedigrees of their select stocks of dogs and cattle and horses, it seems not too much to hope that some day men and women may be willing to safeguard the interests of their own progeny with at least as much assiduity.

Such illustrations as those just given will serve to show the eminently practical character of the new eugenic movement. It is obvious that the individual interests of every intelligent person are directly concerned. This is no academic question; it is a question that concerns the man in the street. It concerns our offspring and the generation in which they will live and have their being. It concerns the entire trend of future civilization. To have gained such clear glimpses of the natural laws that govern human inheritance and to have formulated some clear rules for their interpretation, are not the least among the remarkable achievements of our generation.

VII

MASTERING THE MICROBE

MICROBES AND VACCINES

SIR Almroth Wright, the famous originator of the anti-typhoid vaccine, pointed out in a recent address that nine-tenths of human diseases are minor ills due to microbic infection. Most of us, he declares, have one or another particular microbe as an enemy to which we are peculiarly susceptible.

"Thus," says Sir Almroth, "one man puts up with recurrent influenza attacks, another man with a succession of boils, another man with chronic bronchitis, another with perpetual trouble in the roots of his teeth, another with a continuous discharge from the ear, another with sycosis or acne, another with continual pruritis, another with tuberculous glands, another with phthisis, another with recurrent intestinal attacks, and so on through the whole gamut."

And then the great therapeutist makes this cheering summary: "Vaccine therapy will, I believe, help every man to keep under the particular microbe which besets him."

In other words, each of us may expect in the near future to be able to give himself immunity against the germ that is, so to say, his pet aversion. Indeed, to a very considerabe extent this may be done even

now, thanks to the new vaccine treatment which Sir Almroth Wright and his associates have elaborated. The essential idea of this treatment is a curious one. It is to let any given individual render himself immune to a given disease by developing antidotal bodies in his own system. The development of such antidotes is brought about by inoculating the patient with limited quantities of disease germs that have been killed by heating.

The earliest important application of this idea was made by Professor Wright in connection with preventive inoculations against typhoid fever. It had been suggested by Mr. Haskine that preventive inoculations might be attempted along Pasteurian lines,—that is to say, with living germs; but this seemed hazardous. Then Professor R. Pfeiffer showed that the subcutaneous injection of a *heated* culture of typhoid germs produced a "specific agglutination reaction" in man; and this at once gave Wright a clue which he followed up with wonderful tenacity, and with the ultimate effect of supplying medical science with a new and effective therapeutic weapon.

"The physician of the future will be an immunizator," Wright boldly prophesied when he made his first announcement of experiments with typhoid inoculations in 1902. In the intervening decade, the prophecy has been so carried toward fulfillment that an increasing number of conservative physicians all over the world will echo the words of Dr. William H. Thompson, who says of what he terms the new science of Vaccine Therapy: "The more I see of this recent recourse against microbic infections, the more

I feel convinced that its discovery is to mark a great era in medicine."

PRINCIPLES OF THE NEW METHOD

The method itself has features of picturesque interest, aside from the importance of its results. In principle the rationale of the method is simple enough, though of course a considerable degree of bacteriological skill is necessary in practice.

The essence of the method is this: To cultivate the germs of a given disease in a culture tube; to kill them by heating to about 60 degrees Centigrade; and to inject a small quantity of the culture, incorporating a rather definite number of dead germs, with a hypodermic syringe into the tissues of the person who is to be made immune to disease.

But how, it may be asked, can good results accrue to an individual through the wilful introduction into his system of the germs of disease?

The answer supplies us a clue to the entire mystery of immunity. To understand it we must note a remarkable property of the body tissues. It appears that one extraordinary characteristic of the cells of living animal tissue is this: They attempt to repel any attack made upon them by producing an antidotal substance specifically calculated to neutralize or oppose the attacking agent.

If a noxious bacterium finds its way into the blood and comes in contact with the tissues, the tissue cells (and also probably the white blood corpuscles) at once endeavor to produce substances that will antagonize that particular bacterium in several char-

ANTI-TYPHOID INOCULATION

acteristic ways. These substances are so-called (1) anti-toxines that neutralize the bacterial poison; (2) bactericides that tend to kill the bacterium; (3) bacteriolysins that tend to dissolve it; (4) agglutinins that interfere with its activities; and (5) opsonins that make it an easy prey for the white blood corpuscles that constitute Nature's body guard of soldiers everywhere patrolling the blood.

These "anti-bodies," various and sundry, are so intangible that the chemist cannot as yet analyze them. Yet they make their presence felt by very definite results. A different set of these antidotes is produced in opposition to each particular kind of noxious microbe. If the tissues are able to produce them fast enough in any given case, the invading microbes are destroyed, and disease is warded off. If, on the other hand, the invaders come in too great numbers, or multiply too rapidly, the antidotes cannot cope with them, and the disease develops.

Now the dead germs that the inoculator introduces in producing artificial immunity carry with them a certain increment of poison, and excite the tissues to production of antidotes precisely as would living microbes. There is, however, the important difference that the dead microbes obviously cannot multiply and so overwhelm their host with the power of numbers. The number of microbes and therefore the quantity of poison introduced can be graduated at will of the inoculator, who is careful to introduce only such numbers as experience has shown will not produce too powerful an effect.

So the tissues are able to manufacture sufficient

quantities of anti-toxins to neutralize the bacterial poisons; the bacteriolysins tend to dissolve the dead germs; the opsonins facilitate their ingestion by the hosts of leucocytes always present in the blood; and presently the invaders have been removed from the tissues and their poison neutralized. In a word, the capacity to form anti-bodies, which is a function of the tissues, has been called into action.

NATURE'S PRODIGAL SUPPLY OF ANTIDOTES

No useful purpose would have been accomplished in all this, however, were it not for a peculiar physiological property of the tissues, in virtue of which they do not limit their response to the mere balancing of the attack made by a bacterial enemy. That is to say, when a group of germs with their modicum of poison is forced into the midst of the body cells, the cells do not content themselves with producing merely enough antitoxin precisely to neutralize the amount of toxin introduced, and enough opsonins to insure the ingestion of this particular host of bacteria and no more. Nature is by no means so conservative as this would imply. She calls on the cells to produce anti-bodies in all haste, and to continue producing them for some time after the precise irritant in question has been eliminated.

If a certain group of, say, typhoid germs has been introduced, how can it be known that this is not a mere advance guard, premonitory of the coming of other hosts? Obviously the only safe course is to assume that such is the case.

So the cells go on for a time producing the anti-

dotes, with the result that a residual quantity of typhoid antitoxins and bactericides, and agglutinins, and opsonins, finding no further host of enemies at hand, passes into the general circulation and becomes a relatively permanent constituent of the blood serum and lymph.

It is in the production of this excess quantity of the antidote to a given bacterial poison that the entire rationale of artificial immunization consists. For now let us suppose that the individual thus treated chanced accidentally to ingest some living typhoid germs in his food or drink. These germs as they enter his blood are at once met by the anti-bodies already there, and are promptly destroyed; whereas in the body of a non-immunized subject, they would have multiplied so rapidly that the tissues could not have adequately met them with the production of antidotes.

THE NEW METHOD IS RIGIDLY SCIENTIFIC

The value of the preventive inoculation against typhoid has been fully demonstrated. The British Army used the anti-typhoid vaccine in the South African war. Then it was introduced into the German army, and used by the American army in the Philippines. Very recently its use has been made obligatory in the American army, and it has been used effectively to check epidemics of typhoid fever among civilians, as at Salt Lake City. An inkling of the importance of this discovery from a merely economic standpoint may be gained if we recall that the annual cost of typhoid in the United States has been

U.T.C. Library

estimated at no less than three hundred and fifty million dollars. This estimate was made by Dr. George M. Kober, in a paper read before the White House Conference of Governors, in 1908.

Though this inoculation against typhoid marks a new and most important departure in medical science, it must not be inferred that it constitutes an entirely novel procedure. Jennerian vaccination agaist smallpox, and Pasteur's celebrated inoculation against anthrax and against rabies are illustrations of immunization produced by the introduction of a virus attenuated in strength or limited as to quantity. But the novelty of Wright's experiments consists in the fact that they were attended at all stages by careful and systematic bacteriological observation (whereas in the case of smallpox and rabies, the germ had not yet been isolated); and in particular that the effects of the inoculation were observed and tested by an entirely new method.

This new method is based on the observation of the so-called opsonic index. Being briefly interpreted, this means a test of the quantity of anti-bodies present in the blood as demonstrated by the rapidity with which the white blood corpuscles are observed to ingest disease germs with which they come in contact. The more "opsonin" present, the more readily and rapidly the swallowing of germs by the blood corpuscles goes on. Actual count of the number of germs ingested, on the average, in a given time, gives the microscopist information about the condition of the patient's blood that could be gained in no other way. Professor Wright and Dr. Douglas discovered this

important test in the course of their experiments with typhoid. The discovery placed in their hands for the first time a method of accurately testing the response which the tissues of the body make in any given case of bacterial poisoning.

The results of such observations are of the greatest practical importance. It was found, for example, that after a patient is inoculated with a certain quantity of devitalized disease germs, his "opsonic" index for a time falls; showing that the tissues are not able immediately to neutralize fully the weakening effect of the poison. Wright terms this period the "negative phase."

But presently, in case the inoculation has been properly apportioned in quantity, the index rises,—in token that the blood is being surcharged with antitoxines. This so-called "positive phase" presently reaches a maximum and then begins to recede. Repeated inoculations, however, carry it to a relatively high level, in token that the blood is for the time being highly charged with protective anti-bodies and opsonins. This is the condition of immunity. It is the condition of a patient for a time after his recovery from an acute infectious disease.

But if the repeated inoculations had been made during the "negative phase," the system would have staggered, as it were, under the increasing burden, and injury instead of good would have resulted. This it appears had often been the case in the use of Professor Koch's widely heralded "tuberculin," a bacterial vaccine, before the opsonin test was known. Among the first practical results of the new method

was to show the physician how to regulate the dosage of tuberculin and thus restore to use a discredited remedy. A modified tuberculin, made from the bodies of tubercle bacilli, is to-day in use as an effective immunizing and curative agent against the "great white plague."

THE NEW METHOD EXTENDED TO A VARIETY OF DISEASES

From the above explanation it would appear that the vaccine treatment is chiefly a preventive measure. But it soon occurred to Sir Almroth Wright that the method has wider possibilities. After his signal success with the anti-typhoid inoculation, he began devoting himself to generalizing the method and applying it to the treatment of a great number of bacterial diseases.

Notwithstanding all that has been written on the subject, few people perhaps are fully aware of the extent to which bacteria are responsible for human maladies. It is perhaps not going too far to affirm that no disease to which flesh is heir is entirely free from the possibility of complications arising from the action of noxious germs.

An inkling of the true state of affairs may be gained from the observation that there are at present known to the microscopist more than a score of distinct species of micro-organisms that produce human maladies; while numerous others as yet not isolated make their presence known through such infectious diseases as measles, scarlet fever, and smallpox, the germs of which have not as yet been discovered, though their effects are so familiar.

Leaving aside doubtful cases, some of the germs actually recognizable under the microscope at the present stage of bacteriological science are those causing such widely varying diseases as typhoid fever, diphtheria, tetanus, pneumonia, tuberculosis, influenza, blood poisoning, malaria, syphilis, boils, acne, suppuration of wounds, plague, cholera, cerebro spinal meningitis, dysentery, Malta fever, common colds, Riggs disease, anthrax, glanders, sleeping sickness, and rabies.

Such a list suggests that the possible range of application of a method aimed directly against infectious bacteria is almost limitless. The most obvious application is to cases of localized infections, such as boils, ulcers, and infective inflammation of the lungs. the heart, the kidneys, or of the marrow of the bones. Here the local tissues may not be able to produce anti-bodies rapidly enough to overmaster the invading bacteria, which multiply with astonishing rapidity; and in that event the diseased condition may become chronic. Often there is in effect a drawn battle, in that the tissues manage to keep the infection from spreading beyond a certain area, yet cannot wholly banish the invaders from the system.

In such a case, the theory of vaccine treatment, as practiced by Wright and his followers, is to call up reinforcements from outlying regions of the body. Here is a case, let us say, in which colonies of bacteria have found lodgment on the mucous membrane lining the heart, causing an inflammation technically known as malignant endocarditis—one of the most intractable and deadly of maladies. The local tissues re-

spond to the best of their ability, producing a certain amount of antitoxin and opsonin. Leucocytes gather and prey on the invaders. But their best efforts serve only to hold the parasites in check, not to overcome them.

But now comes the immunizator to the aid of the local tissues. He makes a culture of bacteria of the species in question; kills the bacteria by heating; and injects a certain number into the tissue of the patient's arm or leg. An intense reaction at once sets in at the site of inoculation, and a relatively large quantity of anti-bodies and opsonin is liberated into the blood stream, and presently finds its way to the seat of war, so to speak. These reinforcements may perhaps turn the tide of what might otherwise have been a hopeless battle. Cases of inflammation of the heart have been cured in this way that until this new method was introduced would have been beyond the reach of medical skill.

MIXED INFECTIONS

Of course the actual application of the new method is not always so simple as this illustration may seem to imply. For one thing, infections are very generally "mixed,"—that is, due to several bacteria. Thus, for example, the ulceration of the lungs that characterizes tuberculosis, though primarily due to the invasion of the tubercle bacillus, owes a large part of its virulence to the coming of a quite different germ called staphylococcus—the germ that causes ordinary abscesses and ulcerations is superficial tissues. So it is often desirable in cases of tuberculosis to ap-

ply inoculations of staphyloccocus vaccine no less than of tuberculin.

Similarly in pneumonia, half a dozen bacteria may be found associated with the pneumococcus.

But these complications may not be dwelt on here. Suffice it that the general method of vaccine therapy, as developed by Sir Almroth Wright and his associates, has taken its place in spite of ardent opposition as a remedial method of extraordinary promise.

It should be added that the method has proved in practice to have possibilities of application lying beyond what even its originator hoped for it. Wright himself expressly declared, as recently as 1903, that we cannot hope to apply the method to the treatment of *general* infections that are already under way. That is to say, he felt that the utility of the vaccine treatment in such a disease as typhoid must consist in preventive inoculations rather than in remedial applications in cases of typhoid already developed.

Yet we find that a large number of physicians recently have used the anti-typhoid vaccine in cases of developed disease, and seemingly with the most gratifying results. Many such cases are detailed in an article in the *Medical Record* of June 24, 1911. This phase of the treatment still has controversial aspects, however, and involves matters too technical for discussion here.

THE GREATEST ACHIEVEMENT OF CURATIVE SCIENCE

A writer in the same medical journal under date of June 3, 1911, says: "The value of Wright's vaccines in the treatment of various infections is now

generally conceded by scientific men. If it is true that by means of bacterial inoculations we have the power of raising the anti-bacterial power of the blood, we must all admit that Wright has really given us the 'most valuable asset in medicine' and that his discovery of a means of successfully combatting infectious micro-organisms merits to be recorded as the greatest achievement of curative science and one of unrivaled importance to the world at large."

Speaking in detail of the work at St. Mary's Hospital in London, which is now the seat of Sir Almroth Wright's activities, the writer continues: "Even a skeptical observer will, I think, soon become convinced of the value of vaccines in bacterial infections from watching for several weeks the patients who return for regular treatment to these clinics. The results in many cases are so brilliant and striking that one can scarcely refrain from enthusiasm."

To the truth of this estimate I can personally testify. I have been privileged to observe at first hand Sir Almroth Wright's application of the vaccine therapy at St. Mary's; and I came away filled with enthusiasm that I have no inclination to restrain. In Sir Almroth Wright himself I had found one of the most inspiring and interesting personalities among contemporary men of science; in his method I seemed to see the inauguration of a purely scientific therapeutic measure that should ultimately give man complete mastery over each and every variety of noxious microbe.

Perhaps it is not too visionary to indulge the ex-

pectation that the physician of the future, armed with the new weapons of the immunizator, and co-operating with the hygienist, will pursue the deadlier germs until many of them become extinct species. Man has exterminated hosts of friendly beasts. He should be able to wage equally successful warfare against the enemies that know no habitat but his own body, yet which have been chiefly responsible for reducing the average age of the race to about half its normal span.

Hitherto the physician has been fighting in the dark against these hosts of malignant microbes. But the microscopists of a generation ago revealed the enemy, and the immunizator now places in our hands the weapons for their annihilation.

VIII

BANISHING THE PLAGUES

"A VERY small, frail man; obviously nervous in temperament and doubtless on occasion irritable, but in our interview most gracious."

I find this entry in my note book in reference to a recent visit to Paul Ehrlich at his famous laboratory in Frankfort on the Main. As I recall the occasion, the picture of the man that comes to my mind emphasizes the appearance of alertness, quickness of apprehension, nervous energy of action that characterize the great scientific investigator;—traits that doubtless account in no small measure for his achievements.

But there also comes to mind the recollection of a seemingly naive personality no less characteristic of a man whose life has been chiefly spent viewing the world through a microscope and looking beyond the limits of the visible to picture in imagination the activities of unseen molecules and atoms.

I recall the obvious and open pride, the boyish enthusiasm, with which the great savant beckoned me to one side of his room to inspect some wax models showing hands of afflicted persons before and after treatment with his newly discovered remedy "606"—of which all the world has now heard.

PROFESSOR PAUL EHRLICH IN HIS LABORATORY

"Aren't they wonderful!" he exclaimed. His eye twinkled, and he whispered as if in confidence: "You know if I were to put them in the fire they would melt." Then after a pause: "That is why I do not put them in the fire." A hearty laugh followed, indicating that the discoverer of "606"—and the propounder of the subtlest theory of vital action in connection with disease and immunity that has ever been suggested—regarded this as a very clever witticism.

Nor could the visitor fail to enter into the spirit of the recital. There was a delightfully child-like simplicity in the way of speaking, as also in the manner of the famous investigator as he posed for his photograph, that quite won the heart. Did you expect a disquisition on some obscure phase of science? Instead of this the savant makes a witticism and offers you a cigar, assuring you that smoking is the greatest pleasure of life. Moreover, the entire manner and speech of this greatest living authority in the field of experimental medicine seemed to betoken the modesty, self-forgetfulness, simplicity of view that always—or almost always—characterize the truly great personality.

THE DISCOVERY OF SALVARSAN

The work which brought the name of Ehrlich to the attention of the general public throughout the world in the year 1910 was the discovery of the specific cure for syphilis, which was given to the world under the name of "606," and which was subsequently christened salvarsan; a more soluble form

of the drug soon after being synthesized and christened neo-salvarsan. This drug, when injected hypodermically into the tissues or into a vein has the extraordinary property of searching out the so-called spirochete that causes syphilis, and killing this germ without injuring the unwilling host in whose blood and tissues it has found lodgment. The drug is therefore a specific in the most restricted use of that word. It is aimed to destroy a particular germ, and it accomplishes this purpose in a large percentage of cases at a single dose.

The discovery of this remarkable specific did not come about by accident. The drug was nicknamed "606" because 605 syntheses of allied drugs had been made unsuccessfully, from the same derivative (atoxyl), compounded of arsenic and a coal tar product. This puts the discovery of salvarsan on an altogether different footing from the empirical discovery made several decades earlier, that drugs extracted from the cinchona plant have specific power against the germs of malaria. In point of fact, the discovery of Ehrlich may be said to have come as the logical sequence of a line of thought and investigation to which almost his entire working life had been devoted.

The discoverer first became known to pathologists many years ago through his investigation of stains for microscopic tissues. He devised some remarkable compounds through which he was enabled to stain differentially the different types of white blood corpuscles, proving that these curious cells are not all of one family. Elie Metchnikoff had shown that a

function of the white blood corpuscles is to act as a scavenger in the blood, attacking and devouring the noxious germs that find entrance to the body. Ehrlich showed that it is particular tribes of the leucocytes, more especially the ones which came to be known as polymorphs (polynuclear leucocytes) that make up the company of germ-fighters, which Metchnikoff had christened phagocytes or cell-eaters. Another and smaller type of leucocyte Ehrlich christened the eosinophile (lover of eosin) because of the readiness with which it absorbs the eosin stain.

The functions of the less numerous tribes of leucocytes have not been very clearly made out; but their discovery was a step in the revelation of the complexity of the blood which has been supplemented, on the physiological side, by the studies in immunization, and by such remarkable demonstrations as Professor G. H. F. Nuttall's tests through which the genetic relationship of different animals may be shown by examining a few drops of blood serum.

THE SIDE-CHAIN THEORY

Notwithstanding his successes in the anatomical investigations, Professor Ehrlich's interests have all along centered on the physiological and chemical aspects of the problems of medical science. He made very notable contributions to the theory of the new science of immunity not long after the investigations of Von Behring gave the diphtheria antitoxin to the world. Ehrlich experimented with certain vegetable products, notably ricin, a derivative of the castor oil bean. His line of research had to do with rendering

animals immune to these poisons by giving them repeated small doses of the drug. A conspicuous immediate result of these experiments was the development (about 1897) of Ehrlich's theory of immunity, which may be regarded as the most plausible hypothesis hitherto advanced in explanation of the observed facts of immunity to bacterial diseases. Ehrlich called his explanation the side-chain theory.

This very interesting hypothesis, although based on a vast range of observations, is of necessity altogether theoretical. But it has proved of great importance in enabling workers in many fields to visualize what at least are the possible conditions in the human system through which it comes to pass that the person who has recovered from a bacterial disease is very generally immune for a time at least to further attacks from that disease; and also the allied fact that an antitoxin, developed in the system of an animal, may be transferred with curative effect to the system of a patient suffering from the bacterial toxin,—as illustrated in the familiar case of the Von Behring cure for diphtheria.

The side-chain theory in its fully developed form, as expounded, for example, by Ehrlich before the Royal Society of London in his Croonian lecture, in 1900, is a very elaborate hypothesis. It assumes that the toxin produced by a pathogenic bacterium, the poisonous effects of which produce the symptoms of disease, consists essentially of ultra-microscopic particles which may be conceived as having definite forms, varying with different types of bacteria, but uniform in the case of any given toxin.

A graphic idea of what takes place when the particles of a toxin circulate in the blood of a patient may be gained if we think of each poison-conveying particle as having a specific form that enables it to fit into a corresponding particle of the normal cellular tissues somewhat as a key fits into a lock. If the toxic particles are introduced into the system in sufficient quantities, they link themselves in large numbers with the body cells, thereby conveying their poison to the essential living tissues, and disturbing the physiological processes so profoundly as perhaps to cause the death of the patient.

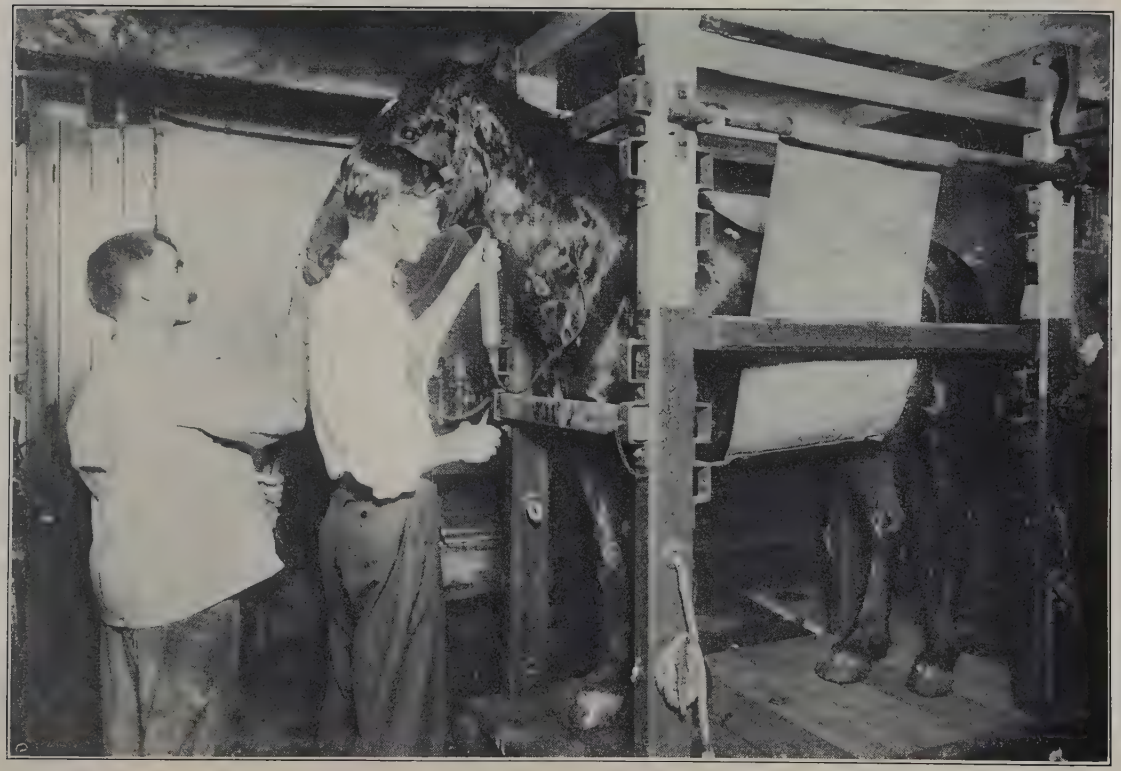
But the bodily cells, if not too quickly overpowered, tend to combat the enemy by sending out what may be called anti-bodies which are of such form as to unite with the toxic particles. Each toxic particle thus united with an anti-body is like a key permanently fitted into a detachable lock. Toxin and antitoxin (key and lock) then float in the blood stream harmlessly, and in course of time are excreted from the body.

As nature does nothing by halves, the cells that send out the antitoxin are not content to produce just particles enough to checkmate each toxic particle. They send out a surplus supply, and these supernumerary particles float unattached in the blood for an indefinite period, ready at any time to attach themselves to toxins of the particular kind that evoke their presence. And persons in whose blood stream such antitoxic particles or antibodies are present are immune to the specific disease whose toxins provoked the sending out of these antibodies.

The graphic diagrams with which Ehrlich illustrates his theory are of course purely imaginary, inasmuch as toxins and antitoxins alike lie far beyond the range of the microscope. But it is always helpful to the investigator of abstruse topics to be able to visualize his work. As I said before, the side-chain theory holds a unique place in this regard. It is applicable all along the line in the studies of immunization, and it has been pretty generally accepted as a working hypothesis. The specific blood tests of Widal for typhoid fever and of Von Wassermann for syphilis have been developed and explained in the light of the side-chain theory; and the new vaccine therapy, which stimulates the cells to act by introducing dead toxic germs, falls equally within its scope. The theory may also be used to explain the very puzzling phenomena of excessive susceptibility to certain protein substances—blood-serum, white of egg, and vegetable albumens, as well as bacterial proteins—to which the term *anaphylaxis* is applied. But perhaps the most important benefits derived from the theory, have grown out of the work of Ehrlich himself, and his immediate associates, in the development of the new chemo-therapy.

THE SEARCH FOR SPECIFICS

The very essence of the side-chain theory, it will be observed, is the assumption that each specific toxin has unit particles of a definite shape and can be combatted only by particles of complementary shape,—just as a given key fits only its companion lock. A vast body of observations in varied fields



DRAWING BLOOD FROM THE VEIN OF A HORSE TO SECURE DIPHTHERIA ANTITOXIN

has tended to support this idea of the specific character of the toxins that are able to produce deleterious effects on living tissues. The idea runs counter to the crude general notion that whatever is poisonous to one protoplasmic cell is poisonous to another. But the evidence strongly supports the new theory. Indeed the fact that an antitoxic serum—such as Behring's diphtheria antitoxin—counteracts the diphtheria toxin and no other, brings the theory of the specific nature of toxins and antitoxins to substantial demonstration.

Such being the case, and it being tolerably clear that the body is able, under favorable conditions, to produce a specific antidote for each type of bacterial toxin, it seemed to Ehrlich within the possibilities that synthetic chemistry might be able to develop corresponding antidotes in the laboratory test tube. His own early work had shown, as we have seen, that certain dyes of the aniline series have the property of staining cells of one type and leaving cells of an allied type unstained; so it occurred to him that by utilizing this selective affinity of the aniline dye, and combining this agent with a drug that is toxic to protoplasm, he might be able to develop specifics which would search out a particular type of disease germ and destroy it without injuring the tissues of the patient in whose system the disease germ lurked and proliferated.

The attempt to put this idea in practice involved almost numberless complications. To mention a single one, it was early discovered that tests of the germicide power of any given drug when made in the

test tube are not to be relied upon. The test must be made in the tissues of the living organism. Obviously a human being cannot be used for this; but fortunately the tests made with the lower animals, notably guinea pigs, rabbits, and mice afford clues that have a large measure of reliability. It is with the aid of these agents that the remarkable work of recent decades in combatting germ diseases has been carried out.

The attempts of Ehrlich to develop antidotes in the test tube were first directed against the protozoal germs of the deadly African disease called sleeping sickness. Ehrlich finally developed a compound of atoxyl having undoubted efficacy in destroying the protozoon, called a trypanosome, that causes the disease. Unfortunately the remedy was found to produce bad after effects, sometimes causing permanent blindness. But the use of the drug salvarsan, which was the next important development, seems to have no bad sequel. It destroys the spirochete of syphilis seemingly without injury to the patient. The complications of syphilis are so numerous that it is usually desirable to supplement the use of salvarsan with other treatment. But the broad general claim that this drug is a specific enemy of the germ of syphilis seems fully established.

THE QUEST OF A CANCER CURE

A further extension of the principle of chemotherapy has been made in the attempt to discover an agent that will act effectively against cancer. Ehrlich, even at the time when his remedy for syphilis

was under way, had a large number of cancerous mice under observation, and other investigators were working along similar lines. In 1912 Professor A. von Wassermann of Berlin announced that he had synthesized a compound of eosin and selenium, which had the specific property of disintegrating cancerous tumors in mice. Not long afterward Professor Ehrlich announced similar results. But in both cases it was specifically stated that the remedy had not been tested on the human subject. There is reason to hope, however, that the synthesis of a drug which has this specific action against the cancerous tissue of a mouse at least points the way to the ultimate application of the remedy or of some modified development of the remedy, to this most deadly and intractable of human maladies.

It was announced early in 1913 that Dr. Leo Loeb of St. Louis, who has long been working at the cancer problem, had developed a compound of colloidal copper which had been tested with at least partially encouraging results on the human subject. Up to this time the cause of the cancer has remained quite unknown. It is not even certain whether the causal agent is a living germ. So the experimenters who are attempting to devise remedies for the malignant growth are working in the dark. Nevertheless many medical men are hopeful that the searchers are on the track of the chemical cure for cancer, and it is easily within the possibilities that this may be discovered before the actual cause of the condition is known. It will be recalled that the causal agent of smallpox is unknown even to this day although the

sure means of its prevention has been available since the time of Jenner.

THE ULTRA-MICROSCOPE

In the attempt to discover the causal agent for smallpox and the allied maladies whose germs have hitherto eluded detection, it has been discovered that a virus capable of transmitting the disease may retain its noxious features after being passed through an unglazed porcelain filter. Similarly Dr. Peyton Rous of the Rockefeller Institute, who has had great experience in cultivating cancer and in transferring the abnormal virus from one animal to another, including mice, rats, and chickens, appears to have produced cancer in an animal by injecting a liquid that had been passed through such a filter. This means that no bacteria of a size visible under the most powerful microscope remained.

It is thought by some observers, that ultra-microscopic particles, conceivably living germs of an order almost infinitely smaller than bacteria, have been detected. The particles in question, whether or not they hold this relation to disease, are observed with the use of the so-called ultra-microscope, which owes its origin to Zsigmondy working in 1901 and to Siedentopf in 1903. The method developed by these workers consists of letting a concentrated beam of light cut across the microscopic field without entering the lens of the microscope.

The rays of light beating against exceedingly minute particles of matter are diffracted or dissipated in every direction, and to the observer who peers

into the otherwise totally dark field of the microscope they will appear as sparks of light. It has been found possible by this method to reveal the presence of particles that are estimated to be not more than ten times the size of a molecule. Such particles lie far beyond the limits of direct vision even under the most powerful magnification.

The effect will be understood if we recall the familiar observation that a beam of light penetrating a dark room through a hole in the shutter, reveals the presence of myriads of motes, floating in the atmosphere, which disappear instantly when they float outside the beam of light. This method was used by Professor Tyndall to test the presence of bacteria in the air, and he found that the naked eye, with the aid of the sunbeam, could detect the presence of spores that otherwise would be invisible except with the aid of a microscope magnifying perhaps a thousand diameters.

The beam of light passing through the field of the ultra microscope, since it is viewed through a magnifying lens, reveals particles infinitely more minute. These exceedingly fine particles are thus observed to be incessantly dancing about in a zig zag motion which would be quite inexplicable except on the supposition that they are being buffeted by the invisible molecules of the solution in which they are found. The degree of activity of ultra-microscopic particles varies, as might be expected, with the strength of the solution; which is in harmony with Van't Hoff's theory of osmosis detailed elsewhere in this volume. It remains to be demonstrated whether the ultra-

microscopic particles hitherto observed bear a definite and causal relation to any disease.

It is always possible that a germ of microscopic size may escape detection because no proper method has yet been devised of staining it and making it visible. It will be recalled that the now familiar bacillus of tuberculosis escaped detection until Dr. Robert Koch devised a special stain in the year 1882; and the spirillum of syphilis (*Spirochaeta* or *Treponema pallidum*), which is a relatively long organism of corkscrew shape, was not discovered until 1905, when Schandinn and Hoffmann devised a stain that renders it visible.

The germ of rabies was unknown until the summer of 1913, when Dr. Hideyo Noguchi, the celebrated Japanese pathologist, now of the Rockefeller Institute of New York, announced the discovery of a protozoal organism in the virus.

RADIUM AND LIFE

That cancer is due to a living organism is suggested, though by no means demonstrated, by the observed fact that in a certain number of cases malignant growths yield to treatment with the new forms of radiant energy. Thus the X-ray has proved curative in some cases of cancer, particularly superficial epitheliomas. The radiations from radium, which consist in part of what appears to be a peculiarly penetrating type of X-ray, have proved even more efficacious.

In 1911 a Radium Institute was established in London. The treatment consists in subjecting the

cancer to the influence of radiations from a small disk coated with a radium salt. Apparent cures are quoted in a large number of cases, chiefly superficial tumors. Deepseated cancers have proved much less amenable to treatment. Nevertheless the pain of inoperable internal cancers is often relieved and their rate of growth checked by the use of radium.

The extraordinary influence of radium and the allied chemicals over living tissues is being investigated by almost every one who can secure a supply of the rare drugs. One of the newest claims is that made by Dr. Saubermann of Berlin, to the effect that radium can restore to a normal condition the hardened arteries from which so many persons suffer in middle and old age. Should this claim be confirmed it will appear that radium has the power to cause absorption of the calcareous deposits to which hardening of the arteries is due. An altogether different function has been ascribed to another radioactive substance known as thorium X, which is a particularly active member of the family of products, each regarded as an element, resulting from the disintegration of thorium.

Thorium X is dissolved in or incorporated with a solution of salt, and tests have been made as to its effects on living tissues. In relatively large quantities it is shown to be inhibitive to the cellular activities. Dr. Francis E. Park, of Stoneham, Massachusetts, reports in the *Medical Record*, the results of experiments which show that seeds soaked in strong solutions of thorium lose their power to grow, and that the drug may prove fatal to dogs. On the other

hand, if given in the right quantities it seems to have curative properties. Its effects on the cells of superficial cancers and of lupus are similar to those of radium. No harmful effects have been discovered from its administration in moderate doses.

But the most curious fact connected with the giving of thorium X in the experiments on dogs was that after twenty-four hours the greater part of the drug administered could be recovered from the red marrow of the dog's bones. It is believed that one function of the marrow is to manufacture the all-essential red blood corpuscles; and some of the experimenters were soon convinced that thorium X has unique power to stimulate this function. Then Professor A. Bickel, of the University of Berlin, used thorium X in the treatment of cases of pernicious anaemia, a disease in which, as is well known, the patient suffers from a paucity of red blood corpuscles. The results of this treatment have proved almost startling. In the case of a patient who received small doses of thorium X by the mouth three times a day, the number of red blood corpuscles in a given quantity of blood increased in six weeks from 960,000 to 4,600,000. In a case reported by another observer there was an increase from 340,000 to 860,000 red cells in twenty-four hours.

In the fall of 1912, Dr. Bickel was summoned to America to treat a case of pernicious anaemia in Greenwich, Connecticut. In this case there was a complication of heart and kidney diseases that prevented a favorable result. But Dr. Park secured from Dr. Bickel a quantity of the drug to use in an

intractible case of his own. He at first used the thorium in connection with electric treatment of bones and the solar plexus. But it appeared that the electricity in some way neutralized the thorium emanation, as the result of the combination was not satisfactory. When the electricity was discontinued, and the thorium given by itself, the patient at once began to gain in a very decided manner. In the course of five weeks not only had his blood count risen from 1,200,000 red corpuscles to 5,280,000, but the general condition of the patient had been transformed from a state of alarming invalidism to one of relative health.

Dr. Park is wisely conservative as to the ultimate outcome, knowing that years must elapse before we can say in such a case that a cure is permanent. But experience seems to justify the conclusion that thorium X is a remedy far more potent than any hitherto known in the treatment of the alarming and by no means rare condition of pernicious anaemia. Unfortunately the drug, like the other radioactive substances, is very rare and costly. It must be given by a skilled physician, and may best be administered hypodermically, preferably injected into a vein.

As bearing on the method of operation of the radioacative elements, the observation of two English experimenters, Drs. Helen Chambers and S. Russ, on the results of subjecting blood to the influence of radium are of interest. So far as their observations went the so-called beta and gamma rays of radium (which are really streams of electric corpuscles and X-rays respectively) had no influence on the blood.

On the other hand, the alpha rays, which consist of electrified molecules of helium, produced important changes in the various constituents of the blood.

The red blood corpuscles, under influence of the alpha rays, were dissolved and their essential coloring matter, known as oxy-haemoglobin, the oxygen-carrying principle of the blood, was changed into met-haemoglobin. This would destroy the capacity of the blood as a carrier of oxygen.

In a somewhat similar way the white blood corpuscles were seen to undergo marked degenerative changes under influence of the alpha rays. During the process of clotting, the white blood corpuscles appeared to move away from the alpha radiating region. This movement is theoretically explained as due to changes in the surface tension of blood serum when radiated.

Not only were the corpuscular elements of the blood thus destroyed, but the specific properties of the blood serum through which normal blood combats the influence of bacteria, were rapidly exhausted under influence of the alpha rays. Thus the substance known as opsonin, the function of which is to make bacteria more readily digestible by the white blood corpuscles, ceased to exercise its characteristic property. In a word, the effect of the radiation was to change completely the character of the blood, and utterly to eliminate the qualities upon which its "life-giving" influence depends.

It is interesting to compare these effects of radium radiation with the observations of those experimenters, notably Mr. John Butler Burke of Cambridge

University, who have sought to generate life in the test tube through the aid of radium salts, Mr. Burke's experiments, which were so much talked about for a time, consisted in sprinkling a radioactive salt upon the surface of a sterilized solution of meat extract or bouillon. In due course there developed in the bouillion minute particles, which increased in size, developed what looked like nuclei, and ultimately multiplied by division very much as do living micro-organisms. In a word these "radiobes," as they were christened, showed very curious resemblance to living organisms, somewhat of the nature of bacteria.

Presently, however, the curious particles were seen to split up into bodies much more closely suggestive of microscopic crystals. Moreover, these crystalline bodies could be dissolved in water, which of course is not true of any bacterium. So it was very clear that the radiobes differed widely from any known form of life.

In general biologists are disposed to consider that the radiobes represent disintegration products of the organic substances in the bouillon rather than protoplasmic bodies. Mr. Burke, however, holds to the view that the radiobes bridge, more or less roughly, the gap between living and non-living matter, and that it is at least possible that they give a clue to the beginning and the end of life.

LIGHT AS A GERMICIDE

It is obvious, then, that the strange radiations that emanate from the new radioactive substances sustain very curious relations to organic matter. Meantime

there are radiations of a more familiar type that have recently been shown to influence living tissues in a way no less interesting.

It has long been known that the rays of sunlight furnish the all-essential stimuli that make possible the work of the vegetable cell in performing the miracles of transforming inorganic into living matter. It now appears that the same light also contains rays that are directly inimical to the life of lower vegetable organisms. The fact was first demonstrated in connection with the treatment of the superficial malignant growth known as lupus, which is due to the presence of the tubercle bacillus, growing in a localized colony, and not tending to spread inordinately, but proving so tenacious of its hold upon the territory already invaded that it was formerly regarded as almost ineradicable even with the use of the knife.

About the year 1895, a Danish physician, Dr. N. R. Finsen, developed a treatment for lupus which consists in exposing the diseased tissue to a concentrated beam of light rich in ultra violet rays; that is to say, in the ethereal vibrations lying just beyond the violet end of the spectrum, and thus composed of light waves that are shorter than the shortest visible ones.

Dr. Finsen demonstrated that these short waves of light destroy bacteria. He was able with their aid to kill the tubercle bacilli in the diseased tissues and thus to cure a very large proportion of cases of lupus. Ultra violet light thus used came to be known as the "Finsen ray."

The germicidal effect of ultra-violet light has since been everywhere recognized. The treatment of tu-

berculosis by direct sunlight, as carried out in hospitals established at high altitudes in the Alps, owes its efficacy to the ultra-violet rays coming directly from the sun. These rays, however, are obstructed by the air, and they have largely disappeared from sunlight at the sea level. They are altogether obstructed by glass; so the sun treatment of tuberculosis must be carried out in the open air. It may be added that the children who receive this treatment in the Alpine hospitals are gradually inured to the cold until they can without discomfort take their sunbaths in the open air stark naked even in the coldest weather.

Practical use has been made of the bactericidal properties of ultra-violet light in the purification of water. But the application of the method to the purification of milk has hitherto proved impracticable because, owing to the opacity of milk, the rays do not penetrate its substance to any considerable distance, and therefore leave the main bulk of the germs untouched.

It would appear, however, that a method has now been found to overcome this difficulty. The new method consists of the use of plates of quartz placed very close together, so that the milk passes between them in a thin film, and is thus sufficiently transparent to be suffused with the light of a mercury vapor electric lamp, the rays of which after passing through quartz are very rich in the short waves that characterize the spectrum beyond the violet.

The apparatus in question is merely a modified form of Mr. Peter Cooper Hewitt's quartz lamp; but rather curiously the experiments in sterilizing milk

with the apparatus are being made in France. The reason for this, Mr. Hewitt explains, is that his quartz lamps are being extensively used in France in sterilizing drinking water, and their efficacy in this connection led to the idea of a similar purification of milk.

The French standards of purification for water are gatifyingly different from those of some American cities. The water is filtered and refiltered until it is so nearly free from all impurities as to attain a degree of transparency that permits print to be read with a telescope through eight meters, or about 26 feet of water. Even water of this degree of limpidity may contain large numbers of bacteria. But when the water has been caused to flow in a zigzag channel past a large quartz lamp, specially devised for the purpose, the germs thus acted on by the ultra violet rays are found to be either dead or so devitalized that they have very slight power of reproduction and hence are innocuous.

Should the present experiments prove conclusively that all the bacteria in milk are similarly killed by the ultra violet rays, the observation will be one of vast practical importance, as means will be afforded of sterilizing milk, which, it would seem, must be superior to any previous method. For the moment, however, the familiar method of pasteurization, which consists of heating milk to about 142 degrees Fahrenheit for a period of three-quarters of an hour, is the recognized method of rendering this beverage wholesome.

The pasteurization of milk is carried out on a very large scale by our modern dairies. After being pas-

teurized the milk is cooled by being allowed to pour down in miniature cataracts over successive pipes, the upper ones of which contain cool water, and the lower ones brine almost at a freezing temperature. The milk is thus chilled in a few minutes and is immediately placed in sterilized bottles.

Some interesting observations were recently made by the New York Health Department in co-operation with the Rockefeller Institute, the subjects being 500 babies in the New York Tenements. According to the observations, as reported by Dr. Wm. H. Park, Director of the Research Laboratory of the Health Department, 2 per cent. of babies using certified raw milk died, as did 8 per cent. of babies using good raw milk, and 14 per cent. of babies using grocery store milk; in addition to which 66 per cent. of the babies using grocery store milk became ill and required medical attention.

Meantime not a single baby died of the group using pasteurized milk.

Dr. Park emphasizes the fact that mother's milk is the best milk for a baby, but his observations show that pasteurized milk is next best. According to Mr. Hewitt, it is believed by the French chemists who are testing the new method of sterilizing milk with the ultra violet rays that milk purified by this method will be even more wholesome than pasteurized milk. To appreciate the importance of the subject, it is only necessary to reflect that bacterial diseases of infancy, the major part of which have their inception in the ingestion of infected milk, constitute the deadliest of all plagues to which the modern

world is subject. One fifth of all deaths occur in early infancy.

A NEW REMEDY FOR CATTLE PLAGUE

Reference has been made to Professor Ehrlich's attempted cure of sleeping sickness. This very fatal disease, which fortunately is confined to the tropics, was studied at first hand by a commission under Dr. Robert Koch, who discovered that the agent of its transmission from one subject to another is the tsetse fly. The germ that causes this disease as already noted, is not a bacterium but a protozoon; that is to say a single-celled animal organism of the lowest type. It has come to be known in recent years that many other tropical diseases are due to similar protozoal organisms. The plasmodium of malaria is also of the same type.

The protozoal germs differ from the bacteria in that they for the most part have a double cycle of life transformations, the two stages of their development being passed in the organisms of different animals. In the case of the malaria plasmodium, for example, as was first demonstrated by the Englishman Dr. Ronald Ross, one stage of development is passed in the organism of a mosquito of the genus *Anopheles*, which transmits the germ to the human subject in whose blood stream it undergoes the remaining stages of its development.

The various tropical contagious diseases are almost without exception transmitted by parasitical insects,—yellow fever, for example, by a mosquito of a different genus from that which transmits malaria, the Asiatic

plague by fleas, and various cattle plagues and at least one disease of the temperate zone, the Rocky Mountain fever, by ticks.

In recent years the study of tropical diseases has become a special department of medicine, but the laboratories in which the investigations are prosecuted are not necessarily located in the tropics. In point of fact perhaps the chief center of such studies is at Cambridge University, England. The biologist in charge of this department of investigation is Dr. George H. F. Nuttall. His official position is that of Quick Professor of Biology. Professor Nuttall's studies of the blood have given him international reputation. In view of his professorship at Cambridge, and the further fact that he is a Fellow of the Royal Society, it is of peculiar interest to note that he is an American. His chief work, however, has been done in Germany and at Cambridge.

The coveted honor of election to Fellowship in the Royal Society was given Professor Nuttall in recognition of a very remarkable series of blood tests of which account has been given in another chapter. A still more recent investigation of Professor Nuttall has to do with a class of tropical animal diseases the germs of which are transmitted from one animal to another by ticks. The most important disease of this class from an American standpoint is the cattle plague known as Texas fever.

The discovery that ticks transmit this disease was made by an American, Dr. Theobald Smith, as long ago as 1889, and a method was devised whereby the animals were rid of the pests by being made to swim

through a tank containing an antiseptic solution. But no remedy for the disease itself was discovered until Professor Nuttall began experimenting two or three years ago with the drug known as trypan-blue.

The investigation was conducted at the experimental station at Cambridge, but the tests have since been repeated on a more extensive scale in South Africa; and it would appear that a valuable antidote for this malignant disease has been discovered. An objection to its use exists, however, in the case of animals that are to be slaughtered for beef, in that the drug is a dye which stains the tissues more or less permanently.

TRANSFORMING THE PANAMA CANAL ZONE

Professor Nuttall has given much atention to another and even more important tropical disease of which man himself is the direct victim, namely, the plague. British interest is kept constantly stimulated by the prevalence of the plague in India, where almost 6,000,000 deaths occurred from this disease in the decade 1896-1907. The subject is of equal interest from an American standpoint because our own ports are from time to time threatened with an invasion of the plague. Tropical diseases in general are given a new aspect by the work that American physicians have recently accomplished in the region of the Panama Canal.

As to the latter, almost everyone knows in a general way that a once pestilential region has been made healthful, but comparatively few persons who have not visited the Canal Zone realize how radical has

been the metamorphosis effected by Col. W. C. Gorgas, U. S. A., the Chief Sanitary Officer, and his associates.

An outline of the work accomplished is given in an interesting article in a recent issue of the *Medical Record*, by Dr. J. Ewing Mears, of Philadelphia. He points out that the Isthmus has been known since the discovery of America as one of the most unhealthful regions of the globe; virtually uninabitable to any but the few natives, who themselves fell victims in great numbers to the deadly scourges of malaria and yellow fever.

When an attempt was made in 1849 to construct a railway across the Isthmus, so many laborers perished from disease that it became a proverbial saying that every railway tie represented the dead body of a workman.

The project of the Isthmian Canal prosecuted by the French from 1881 to 1892 may be described as a hopeless contest waged against disease. "In five years the French lost eleven-sixteenths of their working force, one-third of the number French subjects. Out of the twenty-four Sisters of Charity engaged in nursing in the Ancon Hospital, twenty died of yellow fever. Of seventeen engineers who came on one steamer, sixteen died." Little wonder that the French gave up the fight.

When Colonel Gorgas took charge of the sanitary policing of the Canal Zone in 1904, the conditions had not greatly changed. But within a single year he had so transformed them as virtually to have banished yellow fever, no single case of which has occurred

in the Canal Zone since 1905. It has not been possible to deal with malaria in quite so radical a fashion; but this disease also has been held in check and in a large measure rendered innocuous.

As contrasted with the appalling mortality of the workmen under the French regime, it is sufficient to note that "in the year 1909 the annual death rate per thousand of 11,662 white employes was 6.43 from disease, and 3.43 from violence; total 9.86. Of Americans, of the 8,386, including employes and their families, the death rate per thousand was: From disease 4.05; from violence 2.27; total 6.32." So far as death from disease is concerned, this showing can be duplicated in very few communities of our most healthful regions anywhere in the world. The average annual death rate in the United States is about 17 per thousand.

THE CONQUEST OF TROPICAL FEVERS

Interesting as these figures are in themselves, they become doubly significant when we reflect that the results which they herald have been achieved through the rigid application of preventative measures based upon recently acquired knowledge as to the causation of disease. It is true that Dr. A. F. A. King, of Philadelphia, suggested as long ago as 1883 that malaria might be transmitted by the mosquito, but no one paid any attention to his suggestion, and it remained for Dr. Ronald Ross to show that the mosquito is the real offender so recently as 1898.

Similarly the suggestion of Dr. Nott that yellow fever might be transmitted by the mosquito, made in

1848, remained quite unheeded; as did Dr. Charles J. Finlay's more detailed contention put forward in 1881. It was not until 1900 that the American authorities in Cuba were prevailed upon by Dr. Finlay to investigate his theory. Tests were made in which the lives of several army surgeons were jeopardized and that of one—Dr. Lazear—sacrificed. But in the end the accuracy of the view that Dr. Finlay had so long held was demonstrated.

Then it became clear that malaria and yellow fever are absolutely preventable diseases; that in order to eliminate them it would only be necessary to check the development of two tribes of mosquitoes—for it is a curious fact that only mosquitoes of the genus *Anopheles* can serve as host for the malarial germ, while only those of the genus *Stegomyia* can act in similar capacity for the germ of yellow fever.

The elimination of mosquitoes might seem, indeed, to be no easy task; but that it is feasible in a region under strict military surveillance to guard against them most effectively, is clearly demonstrated in the results achieved by Colonel Gorgas.

BANISHING THE PEST-DISSEMINATING RAT

While yellow fever and malaria are thus guarded against through the waging of incessant war upon the mosquito, the danger of the introduction of plague is minimized by equally strenuous measures directed against the common house rat, since this animal serves as the host of the fleas that are the chief transmitters of the dreaded "black death."

It is now fully recognized that when the plague

gains admission at a port it is brought by rats that have escaped from shipboard. Rats may transmit the disease to allied animals. In this way, for example, many of the ground squirrels have become infected in California; and in one case at least a child acquired the disease through being bitten by one these animals.

Obviously, then, there is no ultimate safety except through destruction of the rats. But in the mean time much may be accomplished in the Canal Zone by either raising the houses three feet from the ground on supports of concrete or other material, covered with tin, so that the rats cannot secure a footing on them. If placed on the ground they must rest on a floor of concrete. The buildings are submitted to inspection at regular intervals; those not in a sanitary condition in the cities must be placed in that condition, if possible, by the owner, or they are condemned and destroyed.

Furthermore direct war has been waged upon the rat. Thus 17,000 of these animals were killed in Panama City in a single year. So rigid has been the inspection of ships, and so effective the warfare upon the rats that the plague has gained no foothold.

THE "TYPHOID FLY" AND ANTI-TYPHOID VACCINE

The chief remaining diseases that formerly ravaged the Canal Zone are typhoid fever and cholera. These diseases also depend to a considerable extent for transmission upon an insect host, the offender this time being the common housefly. War is waged upon the fly, as upon the mosquito, chiefly by destroying its breeding places. So effective have been these pre-

TRAPPING THE TYPHOID FLY

ventative measures that according to Dr. Mears "the fly has now become a *rara avis* within the Zone limits, and is very much less abundant than in the villages and towns of our country." Dr. Mears declares that during his stay in the Canal Zone he saw but a *single specimen;* and we may readily accept his assertion that the comfort enjoyed owing to their absence is very great.

Unlike the flea and the mosquito, the fly does not transmit the disease germs directly to the human subject. Its action is indirect, in that it contaminates the foodstuffs. Food or milk brought from a distance may thus convey typhoid or cholera; but fortunately science is now provided, as we have seen, with the means of combatting these diseases through inoculations that render the subject immune. We have seen that the anti-typhoid vaccine was developed at the beginning of our new century by Dr. (now Sir Almroth) Wright, then of the British Army service in India, but it made its way rather slowly, and its use in the United States Army was not made obligatory until August, 1911. The New York Board of Health began to manufacture it and dispense it for free administration in 1913.

The significance of this new agent of preventive medicine can be realized only by those who have a clear conception as to how great a scourge typhoid fever has always been in the past. In war time it has regularly claimed more victims than the enemy's bullets. Our troops in Cuba, as everyone will recall, were decimated by this scourge, which "stalked through the camp, apparently unrestrained, laying low

one-sixth of the entire command." There is every prospect that all this will now be changed. Typhoid fever, thanks to the new knowledge of sanitation, combined with the use of the preventive vaccine, will be as thoroughly subject to scientific control as smallpox has been since the original vaccine demonstration of Jenner.

AN INSPIRING OBJECT LESSON

The report of the Department of Sanitation of the Isthmian Canal Commission for 1912 shows that the extraordinary work of making a once pestilential region salubrious has been carried one stage farther by Colonel Gorgas and his associates, the death rate among employes being lower than ever before. It appears that in 1906 the death rate among employes was 41.73 per thousand, and in 1907 28.74 per thousand, whereas in 1911, it was 11.02, and in 1912 only 9.18 per thousand. The death rate among white employes was only 3.25 per thousand, and the death rate from disease in the army in the calendar year 1911, was only 2.66 per thousand.

As to specific diseases, we find that in 1907 there were 98 deaths from typhoid fever, in 1912 only 4 deaths from this disease. Pneumonia claimed 328 victims in 1907, and only 57 in 1912; and malaria, which caused 233 deaths in 1906, caused only 20 in 1912.

Considering the death rate of the total population including the cities of Panama, Colon, and the Canal Zone, the statistics show an equally striking betterment in recent years. The death rate per thousand

in 1905 was 49.94; in 1912 it was 20.49. As regards the former scourges of the region, Colonel Gorgas reports as follows: One case of yellow fever on a ship from Guayaquil, Ecuador, was isolated in Santo Tomas Hospital and died there on July 14th. With this exception, no case of yellow fever, plague or smallpox occured on the Isthmus during the year."

It should be understood, however, that the work of making the Canal Zone permanently salubrious is by no means completed. The monthly report for February, 1913, shows that the task of making ditches to drain areas where the mosquitoes breed is still under way, and that there are regions where the deadly *Anopheles*, the carrier of malaria germs, still exists in sufficient numbers to be a menace. The report tells of tests with mosquitoes stained for indentification, in which the marked individuals were found at a distance of 6,000 feet, or considerably over a mile, from where they were liberated.

This fact will be of interest to the local health authorities of many regions of the temperate zone, inasmuch as there has been a prevailing opinion that a mosquito can travel but a short distance from its breeding haunts. It becomes evident that local health boards who wish to protect their villages from invasion by the malaria-carrying mosquito must pay attention to ponds or other reservoirs of stagnant water for a radius of more than a mile.

A long time will doubtless elapse before such conditions as Colonel Gorgas has brought about in the Canal Zone will obtain widely in tropical regions. Nevertheless, the object lesson has already inspired

the authorities of some cities to emulation. An idea of what may be done may be gained from a specific illustration given by Dr. Mears. He says:

"In a visit made in the past winter to South America, I landed in Santos, Brazil, a city of 41,000 population, and one of the best ports on the Atlantic Ocean. A few years ago this port was devastated by raging epidemics of yellow fever. To such an extent did the disease prevail that vessels coming into the port lost in several instances, and very quickly, their entire crews from the disease, officers and men, before they could be unloaded. It was told of one instance in which a vessel lay anchored in the harbor for a period of eighteen months undischarged, with cargo perishing in the hold.

"Inspired by the fact that this city was the greatest shipping port of coffee in the world, the government and municipal authorities inaugurated a system of modern hygienic improvements which banished yellow fever, converting its beautiful harbor from a home of pestilence into an attractive seaside home, with the ships of many nations unloading and loading in guaranteed security alongside of its commodious and well-arranged quays."

Such an illustration presents in a vivid light the enormous economic importance of these newest triumphs of medical science. The conquest of malaria, yellow fever, plague, and typhoid fever will not only metamorphose the conditions of life for the present residents of the tropics, but will open up vast equatorial regions that hitherto have been uninhabitable.

IX

WORKING WONDERS WITH A TOP

IF you were asked to define a compass, you would probably say that it is essentially a magnetized needle, so balanced that it can point to the North Pole. If asked to be a little more accurate you would perhaps explain that the magnetized needle does not point to the true pole, but toward a "magnetic pole" several hundred miles removed from the earth's axis.

If still greater accuracy were required, you might add that the magnetic needle varies the exact direction of its pointing with different longitudes of the earth's surface; that it suffers deflection from various cosmic disturbances, including sun spots; and that it is very notably influenced by the proximity of any magnetic metal, so that the compass on an iron or steel ship requires a variety of adjustments and corrections. But you might affirm, and until very recently you would have been quite correct in affirming, that notwithstanding these defects the magnetic compass is the sole reliance of the mariner in steering his ship in cloudy or foggy weather, and that lacking this instrument, no navigator would dare to head the prow of his vessel very far out of sight of land.

Such being the traditional attributes of the compass, it is rather startling to learn that there has

recently been devised a form of that instrument which utterly negatives all that has just been said. The newest compass, and the one with which eight or ten of our largest battleships are now equipped, has to do neither with magnetic needles nor with the magnetic poles. It is quite uninfluenced by the proximity of metals, utterly disregarding the steel structure of the ship. And in whatever latitude or longitude the ship may lie, this new and revolutionary non-magnetic compass points inflexibly, straight in the line of the earth's true pole or axis of revolution, taking no cognizance whatever of magnetic meridians.

The magnetic compass of the ordinary ocean liner is placed on the upper deck, as far as possible from the steel structure of the ship, and it is carefully corrected for the disturbing influence of the particular ship in which it is placed. After such correction is made, no metal is allowed near the compass. The blade of a jackknife in a man's pocket, or the steel ribs in a woman's corset, if anywhere near the compass, might deflect it sufficiently to disturb the calculations of the navigator.

In the case of the battleship, it is impossible to make permanent correction for all the disturbances due to the steel structures of which the entire ship is composed. The turning of a turret of a warship in action suffices to put the best magnetic compass directly out of commission. And at best the warship is navigated in foggy or cloudy weather with an element of uncertainty as to just what magnetic influences may be disturbing the compass.

But the new compass of which I speak does away

with all these difficulties. It may be placed far down in the depths of the steel hull, away from danger of shot and shell. In fact the chief compass is so placed in our recent battleships, being connected by wire with various smaller repeating compasses which may be distributed about the ship at any desired place. Thus located, deep in the hold, surrounded by structures of steel, near guns and under turrets that are likely to shift position, the ordinary magnetic compass would be absolutely useless. But the new compass operates under these conditions precisely as it would operate on the *"Carnegie,"* a ship which, as perhaps the reader is aware, is composed of wood, and the entire structure of which, so far as possible, has been equipped with non-magnetic appliances in order that it may exert no disturbing influence on the compass, and thus may be used for a survey of the conditions of the earth's magnetism in hitherto uncharted seas.

Add that the new compass, as installed in our battleships, seeks the true north with a force hundreds of times stronger than that which impels the magnetized needle of the ordinary compass to point toward the magnetic pole, and we gain a still clearer impression of the preeminent qualities of this revolutionary apparatus.

But what, it will naturally be asked, is the principle on which the new compass works? What non-magnetic force is there that can conceivably cause a suspended bar of metal to point rigidly to the north however its supports may be shifted? The answer is that the force which produces this extraordinary effect is due to the rotation of the earth itself. The appara-

tus through which the force is manifested is intrinsically nothing more mysterious than a spinning top. The principle involved is that of gyroscopic action. Some one has said that the spinning top is the plaything of children and the marvel of sages. The first proposition expresses a familiar truth; the force of the second will become increasingly manifest as we pass in review some wonderful applications to which the gyroscope has been put in very recent years, one of which has just been suggested. We shall see presently that the same mysterious—yet in a sense quite explicable—force which supplies us with a perfected compass gives us also an apparatus that will prevent a ship from rolling at sea; an allied apparatus that will balance a railway car on a single rail; and yet another apparatus that will stabilize an aeroplane, holding that craft on an even keel in the midst of tempests and fluctuating air currents, with a facility far surpassing the most dexterous efforts of the most accomplished human aviator.

There are other minor feats of stabilizing also which we shall find not without interest; but these three major ones suffice to establish the gyroscope as one of the most wonderful of devices. The results of its operation seem weird to the point almost of incredibility. Yet the principle on which it operates is fully exemplified in the action of the spinning top with which every child plays. Modified tops, ingeniously suspended, may perform not only all the feats just outlined, but may tangibly demonstrate the fact of the earth's rotation. The latter feat was accomplished more than half a century ago by the famous

French physicist Foucault. But the practical applications of the principle, with which we are here chiefly concerned, are triumphs of the science of our own day.

HOW THE GYROSCOPE WORKS

What, then, is the gyroscopic principle" that can work such wonders? Fundamentally, its basis is this simple fact: A spinning top or heavy body of any kind so placed that it can rotate on an axis tends always in virtue of the momentum due to its rotation, to maintain its axis in a fixed position. The rotating body may be moved in a direct line in any direction whatever quite as freely as if it were not rotating, provided no attempt is made to change the direction of its axis. But against any change in the direction of the axis it manifests a resistance of which a non-rotating body gives no evidence.

The principle may be simply illustrated by spinning a bicycle wheel on a hub held in the hand. It will at once be evident that it may be moved upward or downward or latterly or diagonally, quite as well in motion as at rest, provided the axis of the hub is kept always parallel with its original position. But the moment an attempt is made to shift this axis, as by bending the wrist, the resistance of the wheel will be felt. The same principle may be exemplified in an even more familiar way by rolling an ordinary hoop, which owes its stability solely to its gyroscopic action, and which, as every boy knows, resists an attempt to overturn it in a very curious fashion.

To demonstrate just what is the peculiar feature

of this resistance, it is necessary to experiment with a gyroscope suspended in gimbal rings in such a way that it has freedom of motion in three directions. That is to say, the axis of the spinning wheel is fixed in a ring which itself can revolve at right angles to the axis, this ring being also free to revolve in a second outer ring.

If now, a gyroscope so adjusted is set rotating, with its axis in a horizontal plane, and an attempt is made to shift the axis horizontally, the actual shift will not be horizontal, but directly upward or downward. But if, on the other hand, an attempt is made to shift the axis upward or downward, the actual shift will be horizontal. In other words, the resultant motion when any force is applied to the axis of the gyroscope is a shift at right angles to the direction of the force; at right angles therefore to the shift that would take place if the wheel were not spinning.

It is necessary to get this anomalous but invariable gyroscopic action fairly in mind in order to understand the stabilizing effects that are produced with this wonderful apparatus. It should be recalled also that the anomalous movement of the gyroscope is called precession, and that the force which causes it to shift its position is called a precessional force.

With these simple technicalities in mind it is possible to understand all the results attained with the use of the gyroscope.

UTILIZING THE GYROSCOPIC PRINCIPLE

Foucault's demonstration that the earth revolves was made with the gyroscope as long ago as the year

1851. His experiments consisted of spinning a gyroscopic top, swung in gimbal rings allowing it freedom of motion in all directions, in an ordinary room for long periods continuously. The axis of the gyroscope retains its position in space, but inasmuch as the motion of the earth constantly changes the position in space of the room in which the gyroscope is suspended, the axis of the top seems slowly and regularly to swing about, as gauged by the walls of the room. The degree of shift and time required to describe a certain arc accord perfectly with what would be calculated on the supposition that the gyroscope itself is stationary and the earth in rotational motion. Of course no one had doubted that the earth really does rotate, but Foucault's demonstration was none the less interesting and spectacular.

While Foucault's experiments with the gyroscope were widely heralded and aroused great interest in the scientific world, they did not lead immediately to any practical applications of the gyroscope. The first successful attempt to utilize the principle of gyroscopic action in a practical way was made many years later by Lieutenant Commander Obry, an Austrian naval officer who used the gyroscope as a means of directing a torpedo. It is said that prior to the use of this device the "torpedo was little more than a possibility in warfare, but since that time the gyro-gear has been very highly developed and has been the most potent factor in making the torpedo an efficient instrument of war."

Subsequently attempts were made by a number of experimenters to utilize the gyroscope as a stabil-

izer for ships to prevent their rolling at sea. Prominent workers in this field were Sir Philip Watt, Professor Biles, and the elder Freud in England and in Germany Herr Frahm and Dr. Schlick. Mr. Louis Brennan, in England, developed in 1907 a monorail car, balanced by a gyroscope, which excited great interest when exhibited before the Royal Society. After this numberless workers took up the problem, with reference to one or another of its aspects; but no one else, perhaps, has attained so large a measure of success as the American, Mr. Elmer A. Sperry, who has had the assistance in much of his experimental work of the young engineer, Mr. H. C. Ford, and of Mr. Carl Norden. It is the Sperry gyroscope in its various applications that I wish chiefly to describe in the ensuing pages.

THE GYROSCOPE COMPASS

When Foucault made his classical experiments he stated that a very pretty demonstration might be made by pointing the axis of the gyroscope at a star and noting that the axis continues to point toward the same star. "If we select a suitable star," he says, "or if we aim at one of the points of the heavens which appear to be moving most quickly, the axis of rotation when carefully examined will be found to share the same apparent displacement and will give emphatic evidence of the earth's movement." But he adds: "Of course, one should not point the axis in the direction of the polar star, because this star, not having any apparent movement, the instrument would act similarly and not indicate the earth's motion."

Commenting on this, Mr. Sperry says: "What better compass could one wish than that suggested in the last clause of the above quotation from the original writings of Foucault?" And a moment's reflection shows the force of this suggestion. The axis of a gyroscope pointed at the pole star, that is to say due north, will obviously constitute a compass of a novel and important kind.

Such an apparatus, however, without further modification, would by no means serve as a practical ship's compass; for in the first place it would require to be sighted or aimed before it would be of any service, and secondly, it would have no power to readjust itself should it by any chance be thrust out of position. A practical compass must obviously be one that can find the north for itself and return to position if deflected. In order that the gyroscope shall meet this test, it is necessary to restrict its freedom of action. Suppose, for example, that the rotating wheel were suspended in such a way that its secondary axis must maintain a horizontal position, though free to oscillate and point in any direction in the horizontal plane. It appears, rather paradoxically, that such restriction is equivalent to putting the gyroscope in harness and making it serviceable.

How this comes about will be understood if we reflect that any object here at the earth's surface that maintains a horizontal position in any direction other than that of the meridian is in reality constantly changing its position in absolute space. Lay a pencil on the table before you, placing it in the east and west line. Obviously the position of that pencil in

absolute space shifts moment by moment. Six hours from now it will be at right angles to its present position, as it will have gone a quarter way round our globular earth in the meantime. But suppose, now, that the pencil represents the axis of a heavy gyroscope that is free to oscillate but is held in horizontal plane by force of gravity. Recall, then, what happens when you attempt to tip the axis of a gyroscope as the movement of the earth will tip this one. The axis does not move in the direction in which you attempt to tip it, but at right angles to that direction. And that means, in this case, that the axis must swing about in the direction of the north and south line,—just as if you turn the pencil about on the table without lifting it.

Suppose you turn your pencil until it lies straight north and south on the table, and then as before consider its relation to the rotating earth. A moment's reflection will show that the pencil now occupies the one only position in which it will remain parallel to its present position hour after hour. Six hours from now, or twelve or twenty-four hours from now, it is still aimed in the same direction. And of course the same thing holds true for the axis of our gyroscope. When it finally reaches the north and south position, it ceases to feel the disturbing influence of the earth's motion. Now it is in stable equilibrium; it will hold its position rigidly unless some new force disturbs it. And if forcibly deflected, it will instantly come again under the torsional (precessional) strain of the earth's motion, and hence will be promptly swung back into meridianal position.

All this is obviously only a roundabout way of saying that the axis of the gyroscope in question is a compass pointing to the true north,—forced into this position by the power of the rotating world itself in conjuction with its own rotation, and held there inflexibly so long as world and gyroscope both continue to rotate.

Such is the theory of the gyro-compass. In the practical application of the theory there is opportunity for the display of great inventive ingenuity. German inventors have sought to solve the problem by floating the gyroscope on mercury. Messrs. Anschutz-Kaempfe and Martienssen have attained a measure of success in this way. But Mr. Sperry thinks that the same end may be attained to far better advantage by giving the entire gyroscopic apparatus the form of a pendulum, its secondary axis thus being held in horizontal position by the force of gravity.

After long series of experiments, Mr. Sperry has perfected a gyro-compass that is a highly efficient and practical instrument; a better instrument, indeed, in many ways than any magnetic compass ever devised. In proof of practicality, it suffices to note that the Sperry gyro-compass has recently been installed on a number of our battleships, including the *Florida*, the *North Dakota*, the *Utah*, the *Delaware*, the *Michigan*, the *New Hampshire*, the *Kansas*, the *Rhode Island*, the *Arkansas*, and the *Wyoming*. A Brazilian battleship similarly equipped steamed out of New York harbor the other day; and the largest ship in commission, the *Imperator*, carries a gyro-compass of

German make. It is pretty obvious that the non-magnetic compass is the compass of the immediate future.

The actual Sperry gyro-compass, as adjusted deep in the hull of a battleship, is an electrically rotated steel wheel about twelve inches in diameter. The mechanism of the master compass is of course concealed within casings, and a compass card of familiar appearance is adjusted at its face. There is a pneumatic damping system to minimize the disturbances due to motion of the ship. There are also automatic correction dials, which must be adjusted for the latitude and for the speed in knots from time to time. But these may be adjusted as easily as you set a watch, and aside from this the mechanism requires no alteration. The force with which the gyro-compass resists deflection from the true north is almost three hundred times the directive force of the most powerful magnetic compass.

Any number of small "repeating" compasses, connected by wire with the master compass, may be distributed about the ship. These are not properly speaking compasses in themselves; but their dials—which may be placed in any convenient position, horizontal or vertical or slanting—duplicate accurately the record of the gyro-compass.

STEADYING SHIPS AT SEA

This use of the gyroscope to take the place of the magnetic needle is one of the newest developments of applied science. But there are other applications of the gyroscopic principle that are less novel. More

than a century and a half ago, in the year 1744, a British inventor named Serson conceived the idea that a spinning top with a polished upper surface might be used to supply an artificial horizon at sea, in order that observations might be made when the actual horizon was hidden by clouds or fog. The British admiralty was disposed to test the apparatus, but the inventor was lost in the wreck of the ship *Victory*. The idea, however, has been utilized in recent years, and with the modern gyroscopic apparatus it is possible to secure an artificial horizon that serves the navigator an admirable purpose.

A much more important possibility of utilizing the stability of a revolving wheel is concerned with the attempt to prevent ships at sea from rolling. The first important effort to make sea voyaging more comfortable with the aid of the gyroscope was made by Sir Henry Bessemer, the famous English innovator in the steel industry. Bessemer, however, did not attempt to apply the principle to the stabilizing of an entire ship, but only to a single room with a movable floor constructed on a Channel steamer. It is said that he spent a very large sum in the attempt to put the idea into practice, but the experiment failed utterly.

Bssemer's futile experiments were carried out about the year 1880. No one seems to have taken up the task that he abandoned for a good many years, and then the experimenters who thought that the gyroscope might be of aid in making ocean travel less disagreeable, turned their attention to the more comprehensive problem of stabilizing the entire ship.

The first really successful effort in this direction was made by the German engineer Dr. Otto Shlick, who in 1904 was able to make a successful demonstration by installing a gyroscope apparatus on a torpedo-boat called the *Sea-bar,* discarded from the German Navy.

Dr. Schlick's gyroscope consisted of a powerful fly-wheel installed in the hull of the ship on a vertical axis, and so adjusted that the entire mechanism is free to oscillate lengthwise of the ship. In action, stimulated by the precessional motion engendered by the rolling ship, its mighty mass, pivoted on lateral trunnions, lunges forward and backward with terrific force, as if it would tear loose from its bearings and dash the entire ship into pieces. It causes the ship to pitch a trifle fore and aft as it does so; but meantime it steadies the lateral motion. Some critics think, however, than its use may not be unattended with danger since the revolving wheel of the Schlick gyroscope, to be effective, must bear an appreciable relation to the mass of the entire ship. Such a weight, revolving at terrific speed and oscillating like a tremendous pendulum, obviously represents an enormous store of energy. Should such a gyroscope in action break loose from its trunnions, it might go through the ship with the devastating effect of a monster cannon-ball.

It was not at first seen how the obvious disadvantages of the Schlick gyroscope, incident to its enormous size, could be overcome. But presently Mr. Sperry devised an ingenious method that has enabled him to utilize the gyroscope as a stabilizer of ships without necessitating the employment of revolving or

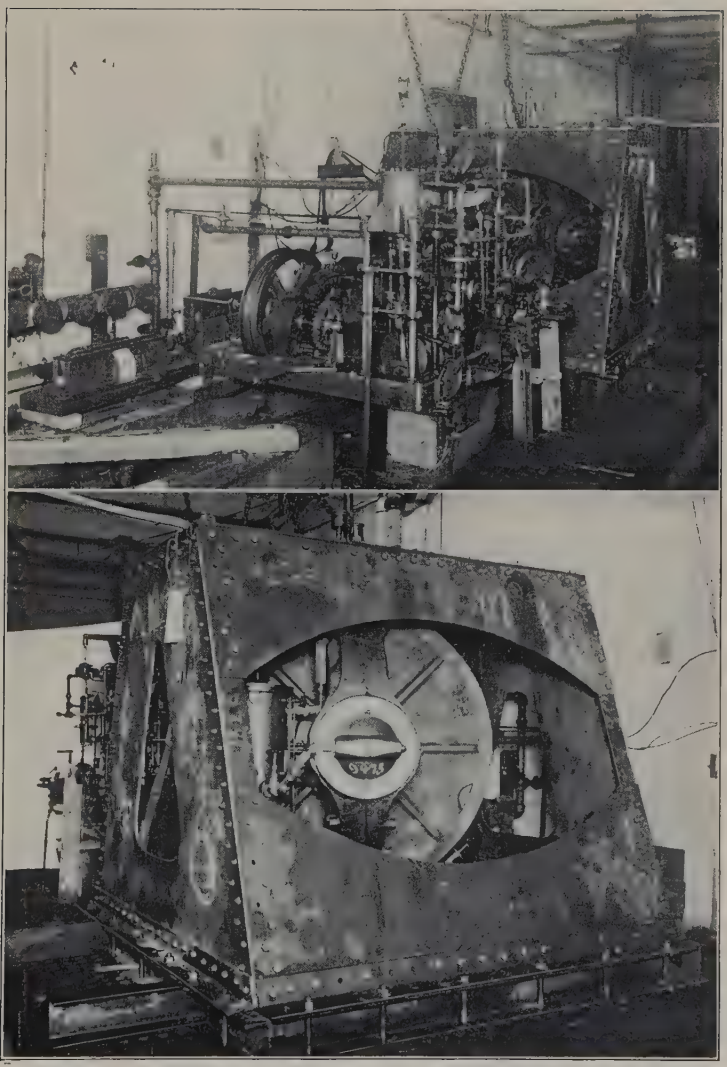
oscillating masses of unmanageable size. The principle on which the Sperry ship-steadying gyroscope works is that of anticipating the rolling motion of the ship, and, so to say, nipping it in the bud. The Schlick gyroscope could not get into action until a precessional stress had been brought to bear on its axis by the actual rolling of the ship. But Mr. Sperry conceived the idea of giving a precessional thrust to the axis of the gyro with the aid of a steam engine; such thrust being timed by the action of a very small gyroscope which would feel the slightest departure from the level.

The large active gyro is arranged with a horizontal axis lying athwart the ship. The so-called precessional engine is so arranged that when it operates it gives a horizontal thrust to the end of the gyroscope's axis lengthwise of the ship. Such a thrust obviously causes the axis of the gyroscope to attempt to precess in a vertical direction, thus straining at its bearings—rigidly bolted to the ship's steel framework—in such a way as to resist the tendency of the ship to roll. There is no marked oscillation of the mass as in the Schlick gyroscope, and as the precessional engine is brought into action almost in anticipation of the motion of the ship, a relatively small expenditure of power suffices to hold the ship on an even keel.

A curious additional possibility with the Sperry gyroscope is that, with the aid of the precessional engine, the apparatus may be made to bring such a strain on the ship as to cause it to roll in perfectly smooth water. This was demonstrated on the U. S.

S. *Worden,* which while tied up at the docks, was made to tip in such a way as to strain at its hawsers. Thus it will be possible to incline the deck of a warship at any desired angle and hold it there, to facilitate firing the guns at long range. The capacity to make the ship roll with gyroscopic aid will be of use on occasion in working the hull loose from a sandbar; also, in case of ships on our Great Lakes, to enable the vessel to break through the heaviest ice. A very slight rolling motion will prevent ice from forming in still water about the hull of the ship. Thus traffic on the lakes will be greatly facilitated. Meantime the same gyroscope which rocks the boat to break ice or to prevent its formation will serve the opposite purpose of making the ship steady in rough water, to the greatly added comfort of passengers and safety of cargo.

Mr. Sperry tells an anecdote in connection with the experiments preliminary to installing a plant on the *Worden* which is worth repeating. "These experiments were being made with models to simulate a ship, and it had been shown that the principle of the active type of gyro would enable us to do exactly what we had claimed we could do. After the experiments were over an old bluejacket who had been helping us asked me what it was all about, and I told him that the experiments just completed proved that we could prevent ships from rolling. He turned to me and in a very disgusted manner told me that if I had ever been to sea I would know that it was foolish to try to do anything of the sort. 'Why,' he said, 'when you get out there in the middle of the ocean



TWO VIEWS OF THE SPERRY SHIP-STABILIZING GYROSCOPE
The upper figure shows the precession engine in the foreground

what have you got to hang on to to hold her?' He was right. You do have to have something to hang on to.' And that something must be very powerful. In the case of the stabilizing gyros it is the tremendously augmented inertia of the rotating mass."

It is apparent, then, that even with the Sperry gyroscope it is necessary to use a revolving wheel of rather formidable size. It appears, however, that contrary to what might be expected the power required for control of the precession engine is trifling. This is due to the fact that in rolling, as reflection will show, the constant tendency of the ship is to do precession-wise work upon the gyro. Moreover the weight of the gyroscope itself is by no means so great as might be anticipated, inasmuch as the rotation constitutes "a multiplier of tremendous magnitude, even though the actual rotative speed is relatively low."

It has already been fairly demonstrated that the Sperry gyroscope operates effectively when its mass is but a fraction of the mass of water in the so-called damping tanks, which have hitherto been the most practical means of minimizing the rolling of ships. It is further estimated that the power required to operate the gyro even in bad weather is only a fraction of the power wasted in propelling a ship provided with bilge keels, which, as is well-known, have limited influence at best in preventing the ship from rolling.

STABILIZING LAND VEHICLES

The utility of stabilizing ships with the gyroscope seems pretty clearly demonstrated. As to land ve-

hicles, the case is not quite so clear. Reference has been made to Mr. Louis Brennan's gyro-car, exhibited in 1907. Two years later Mr. Brennan constructed a car of commercial size, capable of carrying forty or fifty passengers, and clearly demonstrated the feasibility of balancing this vehicle on a single rail with the aid of his gyroscopic mechanism. Whether or not the idea of a mono-rail vehicle will prove commercially valuable remains to be seen. Mr. Brennan's original idea was that such vehicle might have utility in time of war, being operated over a temporary rail which could obviously be laid with far greater facility than an ordinary double rail track. It is possible that a much more extended use may be found for the mono-rail vehicle.

In any event the demonstration of the principle of balancing a land vehicle with the aid of a gyroscope has great interest. The principles involved have already been explained, but it will be obvious that a vast deal of ingenuity was required to devise a mechanism through which the principle would be sucessfully applied to the feat of balancing a car resting on a single line of wheels. Mr. Brennan found the solution with the aid of a gyroscope with the axis placed horizontally, one end of the axis being extended and adjusted in such a way that it will roll along the surface of upper and lower flanges alternately, thus accelerating the precessional movement which would be inaugurated by the tipping of the car.

The effect, briefly, is this: The car tipping tends to displace the axis of the gyroscope downward, but, owing to the curious principle of gyroscope action at

right angles, in reality displaces it horizontally. Such displacement brings it in contact with one of the flanges, and the revolution of the gyroscope itself tends to make the axis roll along this flange. But this roll virtually constitutes a longitudinal thrust on the axis of the gyroscope; and such longitudinal thrust of course results in lifting the axis vertically. This lift brings another part of the axis in contact with another flange attached to the car body, and pressure against this tends to lift the car back to the level, while at the same time the reaction on the gyroscope causes it to precess back to its original position. An incessant cycle of operations of which this is the epitome serves to maintain the car in equilibrium.

A single gyroscope would suffice for this if the car were running on a straight track. But on rounding a curve a disturbing force would be brought to bear on the gyroscope, due to the changed direction of the train, which would result in tipping the car abnormally. To prevent this, a second gyroscope is installed, which will aid the first in balancing on a straight-away course, and counteract the abnormal tipping at the curves; such counteraction being due to the fact that the two gyros revolve in opposite directions.

The balancing feats actually performed by Mr. Brennan s gyro-car are striking, not to say mystifying. If you push against the side of the car with your hand, the car is felt actually to push back as if resenting the affront. If the wind blows against the car, it veers over toward the wind. If the track on which it runs—consisting in the case of the model car of an

ordinary gas pipe or of a cable of wire—is curved, even very sharply, the car follows the curve without difficulty, and, in defiance of ordinary laws of motion, actually leans inward as a bicycle rider leans under the same circumstances instead of careening outward as one might expect. In the case of the large car, forty passengers were crowded at one side, with the result of causing that side of the car to rise, the entire car being balanced securely in this leaning position.

All these anomalies are perfectly explicable, as illustrating the principles of gyroscopic action—namely, the enormously augmented momentum of a rotating body, its tendency to maintain a stable position, and its invariable shift at right angles to the line of force that disturbs its position. In a sense, the stability of Mr. Brennan's gyro-car is no more wonderful than the stability of a spinning top or a rolling hoop. But it is almost impossible to bear this in mind as you watch the curious vehicle, poised for example on a single strand of wire stretched across a gorge and standing there perfectly rigid and altogether secure, or, at mandate of its manipulator, passing forward at low speed or at high with the same secure equilibration. So anomalous does the gyro-car appear when thus exhibited that its feats of automatic balancing seem to bid defiance to the laws of gravitation and to suggest the working of miraculous powers.

STABILIZING THE AIR SHIP

When the power of the gyroscope in stabilizing the monorail land vehicle and the ship at sea had been demonstrated, it was natural that the question should

arise as to whether the same principle might not be utilized in giving stability to the air ship. Indeed, there were those who predicted, before the Wright brothers achieved success, that no heavier-than-air machine would ever fly unless stabilized by gyroscopic action.

The success of the Wrights, who solved the problem of stabilizing the air craft with the aid of warping wings in connection with vertical and horizontal rudders, made the use of the gyroscope seem superfluous. But practical aviators were soon alive to the desirability of some automatic stabilizer, and very recently the question of utilizing the gyroscope in this capacity has been frequently discussed.

To some theorizers it seemed plausible that a relatively heavy gyroscope might be adjusted to the aeroplane in such a way as to prevent its tipping just as the Brennan gyroscope prevents the tipping of the gyro-car and as the Schlick and Sperry gyroscopes prevent the rolling of the ship. But others thought that such a use of the gyroscope would be fraught with danger. An airship is subjected to sudden and irregular stresses from powerful gusts of wind; and it is hardly supposable that a gyroscope powerful enough to defy the strongest currents could be utilized. Yet if a momentary gust did overcome the power of the gyroscope and thrust its axis aside, the precessional effect, tremendously augmented, would bring a strain on the ship which would divert it in an unexpected direction and probably result in wrecking the craft. Indeed, it seems more than likely that many aeroplanes have been wrecked in precisely this

way through the gyroscopic action of their rotating motors and propellers.

Very recently, however, Mr. Sperry has been able to utilize the gyroscope as a stabilizer of the aeroplane in a way to avoid this danger. His solution consists in using two small gyroscopes which operate on the rudders and balancing wings, but which are far too feeble to have any marked *direct* effect upon the stabilization of the craft. One gyroscope acts on the horizontal rudder, the other on the aillerons which take the place of warping wings in the Curtiss aeroplane on which the apparatus was first tested. These gyroscopes may be instantly detached from their connection with the steering gears or re-connected at the will of the aviator by means of a button attached to his steering wheel.

The two gyroscopes act quite independently, one of them having to do with longitudinal and the other with lateral stability. When in operation their response to the slightest tendency of the machine to oscillate is practically instantaneous and their automatic control of the horizontal rudder and of the warping devices is so delicately effective that the aeroplane is kept flying at a given level and almost without a tremor even in a choppy wind where the most skilful aviator would find it very difficult to maintain a safe balance, and impossible to keep the apparatus really steady.
mosts skilful aviator woud find difficulty in keeping the apparatus steady.

If it is desired to ascend or descend, it is only necessary to throw the longitudinal stabilizer out of con-

nection. Moreover, it is possible to adjust this stabilizer in such a way that it will be automatically connected and begin to operate on the horizontal rudder in the event of the machine being suddenly tipped abnormally by an air current, or in case of its being headed into the air at a dangerously steep angle by the aviator. It should be explained that the airman at a great height often finds it difficult to determine just how fast he is climbing, or whether indeed he is climbing at all; and that there is always danger that the machine may be headed upward at such an angle as to lose all power of progression. In such a case the entire aeroplane may slide backward in the air when the aviator imagines himself to be rising, and there is obvious danger that it may then pass altogether out of control and plunge to the earth. The gyroscope stabilizer is believed to prevent the danger of such a disaster, as it will automatically correct the mistake of an aviator who deflects the horizontal rudder at too great an angle.

The observed efficiency of the mechanism that operates the wing-warping devices is comprehensible when we reflect that the gyroscope instantly responds to the slightest attempt to deflect its axis, whereas the human operator—who in the case of the Curtiss machine manages the aillerons with the aid of wires attached to straps about his shoulders—has a comparatively blunt sense of equilibrium and hence does not recognize or respond to the tipping of his craft until it has reached a considerable angle. In an actual flight, with a skilled aviator at the wheel, the aircraft in a chopyy wind wabbled disagreeably despite the

best efforts of the operator unaided by the gyroscope, yet became instantly steady when the button was pressed that put the gyroscopic stabilizer in connection with the balancing wings.

It appears, then, that the gyroscope stabilizer for the aeroplane has a field of operation of vast importance. Seemingly the apparatus should give an added increment of safety to the flying machine under all conditions. It will presumably enable the aviator to rest in the air without jeopardy; and the relief from the incessant strain of perpetual balancing should make long voyages feasible for aviators who have hitherto lacked endurance for such feats. With the aid of the stabilizer it should also be possible for a single airman to take photographs or make maps of the countries over which he is flying, or on occasion to operate the wireless apparatus, sending or receiving messages, or to manipulate a bomb-thrower or a machine-gun in case of a warlike expedition.

In a word, the successful utilization of the gyroscopic principle in its application to the flying machine seems likely to prove the most important contribution that has been made to the art of aviation since the memorable day in December, 1903, when the Wright brothers first demonstrated the feasibility of human flight.

X

THE CONQUEST OF TIME AND SPACE

IN the month of February, 1912, there tied up at a London dock a vessel of about 5,000 tons burthen, which to any casual observer would have seemed a rather ordinary looking steamship were it not for one striking peculiarity,—namely the absence of smokestacks. The vessel flew the Danish flag and bore the name *Selandia.*

The absence of smokestacks marked the vessel as something out of the ordinary. That the craft is indeed very much out of the ordinary was evidenced in a visit paid her by a notable company of British officials, including the First Lord of the Admiralty.

The extraordinary interest thus manifested in the Danish ship is explained by the fact that the vessel was far and away the largest craft theretofore completed—in fact the only large ship then in commission—the propulsive power of which is neither wind nor steam. Ships without sails are common enough; but a steamless steamship is obviously something new under the sun. The *Selandia,* however, is such a ship. Unlike every other large vessel that is not equipped with sails, she has neither coal nor furnace nor steam boilers in her hold. She is the pioneer example of a new type of ship; and if present indications are to be

trusted, her construction marks a new era in maritime annals. It is within the possibilities that craft of this new type are to supersede the steam-propelled ship in the near future much as the steamship has superseded the sailing vessel.

A STEAMLESS STEAMSHIP

The explanation of the mystery is this: The *Selandia* is provided with engines of a new type, the motive power for which is supplied by sprays of oil instead of by steam. The oil spray is not burned in a furnace, but is injected into the cylinder of the engine itself, and, igniting there, expands explosively and drives the piston forward exactly as steam drives it in an engine of the familiar type. The exhaust consists of a practically colorless vapor which escapes through a tube in one of the masts that carry the wireless equipment of the ship. The exhaust from all the engines working at full speed is said to produce less visible vapor than often emerges from the motor of an automobile.

If we contrast this with the volleys of smoke that belch from the funnels of an ordinary steamship, we have a rough measure of the efficiency of the new engine, which consumes and utilizes its fuel instead of sending it up the chimney.

The oil engine which thus threatens the supremacy of the steam engine is the invention of Dr. Rudolf Diesel of Munich. The inventor has had the usual amount of difficulty in bringing his invention to the attention of the commercial world. But the success he has now achieved justifies, in a measure at least,

the glowing predictions in which he indulged in a recent lecture before the Institute of Mechanical Engineers in London.

The lecture was given at a time when the coal strike was at its height; when two and a half million men were out of work in consequence; when British railways were running on half schedule; when many ships were tied up at their docks for want of coal; and when the entire industrial activity of England was temporarily in check.

Dr. Diesel declared that his invention would make a repetition of this disaster impossible. His engine would permanently break the monopoly of coal. He had solved the problem of using liquid fuel for power production in its simplest and most general form. Any of the natural liquid fuels could be used,—and what was more, used simply and economically.

He declared that there is probably as much liquid fuel as coal on the globe. New petroleum sources are constantly being discovered. The world's production of crude oil increases and may be expected to increase. Even at present, forty per cent. of the production of mineral oil, it was declared, would supply the whole naval and mercantile fleet of the world with ample power were they equipped with Diesel engines.

Of course inventors are proverbially sanguine; but in the present case the predictions of Dr. Diesel have back of them a record of accomplishment that insures them very serious consideration. The Diesel engine has passed through a period of probation during which it has been used successfully in

small engines of many types. The *Selandia* was the first large vessel equipped with an oil motor to be put in commission, but numerous other vessels, some of them even larger, are building. The interest of the British Admiralty has already been referred to. It is said that the German Admiralty is building a cruiser to be equipped with two six-cylinder engines each of 6,000 horse power. A sister ship to the *Selandia* was put in commission a few months later, and the East Asiatic Company is reported to have given orders for two similar vessels, and for two cargo vessels, all to be equipped with Diesel engines.

The explanation of the popularity of the new engine is not far to seek. It is founded on efficiency and cheapness of operation. Tests have been made on large Diesel engines, showing the consumption of only 0.38 pounds of fuel per brake horse-power-hour. Marine engines actually in use average 0.4 to 0.44 pounds of fuel per brake horse-power-hour, running under full load.

Contrast these figures with the 1.46 pounds of coal required to produce the same result, and it will be clear that the champions of the new engine are not mere visionaries.

It is estimated that the Diesel engine would drive a ship as fast and as far with 100 tons of fuel as the best steam engine would with 350 tons of coal. As the liquid fuel may be stored in tanks placed in the double bottom of the ship, there is an obvious saving in space that is of great importance. The space formerly occupied by boilers and coal bunkers will be available for passengers and cargo.

The Diesel engines themselves in the *Selandia* occupy about as much space as the engine equipment alone of the ordinary steam plant; but even in this regard a further economy of space will be possible. Meantime the engine room of the new craft is not only guiltless of dust and smoke, but is cool and comfortable. The glare of flame-belching furnaces of the ordinary steamship, along with the torrid heat and the picturesque array of stokers sweltering and begrimmed—are strikingly conspicous by their absence.

How far the Diesel engine has passed beyond the experimental stage will be further evidenced when it is noted that the *Selandia,* a vessel of 370 feet length and 58 feet beam, is not merely a cargo boat, but has accommodation for about a score of passengers who are comfortably quartered in a deckhouse forward of the engines in large cabins having bathrooms en suite. She belongs to the East Asiatic Company and on leaving London started on her maiden voyage to the East. The engines of the *Selandia* are in two sets, each having eight cylinders of 20.8 inches by 28.7 inches giving together 2500 indicated horse power at 140 revolutions per minute. The general appearance of the engine is that of ordinary reciprocating steam engines.

The operation of the engine may be briefly described thus: The upward stroke of the piston sucks air into the cylinder. The return stroke compresses the air to about 300 atmospheres, and hence heats it to a high degree of temperature. A spray of oil is then injected into the compressed and superheated air. The heat of the compressed air ignites the oil

spray spontaneously, so that its combustion is effected without the use of any igniter such as is used with gasoline engines. This obviously simplifies the action of the engine; and the method of operation permits the use of any crude oil.

It will be obvious that the Diesel engine is a modification of other types of oil engines, and not in itself an absolutely new creation. It will be clear, also, that its operation is the four-cycle stroke familiar as the Otto cycle. Like the gasoline engine, it can be so constructed as to operate on a two-cycle principle.

In these respects the Diesel engine affords no novelties. Its unique feature is the utilization of compressed air, which does away with special apparatus for igniting the oil. The fact that crude oil of any type may be employed gives it vast commercial importance.

AN ALL-IMPORTANT MECHANISM

The internal combustion engine, of which the Diesel engine is the newest type, was in some respects the most important mechanism developed in the closing decades of the nineteenth century. Three revolutionary craft—the submarine, the dirigible balloon, and the aeroplane—owe their existence to this engine. With its aid the depths of the sea and the heights of the air are being made accessible.

When we reflect, further, that the conditions of land traffic are being revolutionized, thanks to the automobile, through the same agency, and that the motor-boat is becoming an institution of importance, —even should the Diesel engine fail to drive the

steamship off the sea,—it will be apparent that no review of recent progress would have even a semblance of completeness that did not pay full tribute to the gas or oil engine.

The definitive improvements that gave the gas engine commercial value were made by a German, Dr. N. A. Otto, as long ago as 1876, but the development of a compact, high-speed type of oil engine, largely through the efforts of Herr G. Daimler, is much more recent.

As finally perfected, the internal combustion motor is responsible in our generation for an industrial revolution comparable only to that effected at the beginning of the nineteenth century by its prototype the steam engine.

We have just been introduced to the newest type of oil engine, the Diesel motor. Our further concern is not so much with the gas engine itself as with the space-conquering mechanisms that it has brought into being. The most obvious and universal of these, and the one that up to the present is the most significant as an economic factor, is the automobile. It would be quite superfluous to describe the mechanism or the method of operation of this vehicle, but a few statistics as to its recent development may not be out of place.

AUTOMOBILE AND SUBMARINE

It was estimated that there were 677,999 automobiles in use in the United States in the summer of 1912. It is further estimated that more than 200,000 of these machines were manufactured here in the

year 1911, and not far from a quarter of a million in 1912. The officially estimated value of the materials used in the automobile industry in 1909 is just under a quarter of a billion dollars, and the value added by manufacture ($117,116,000) brings the total value to $336,758,000,—that is to say, about 18 dollars for each and every family in the United States.

These figures are impressive. They become doubly so when we reflect that this colossal industry has been developed in the past fifteen years. In the decade 1899-1909, according to the Census Report, the automobile industry showed an increase of 5,148.6 per cent. in value of product, and 3,278.9 per cent. in number of wage earners. Meantime there are only thirteen other industries that show an increased output of more than one hundred per cent. Stated otherwise, only fourteen industries all told doubled their output in the decade, while the output of motor cars increased fifty fold. The merest tyro can gain an inkling of what that must mean in the way of economic readjustment; but the most expert student of the subject could not guage its full meanings.

In the face of this sudden development of popularity of the self-propelled vehicle, it is interesting to recall that the prototype of the automobile was invented more than a century ago, and that steam-propelled omnibuses were used commercially in England as early as 1830. Public prejudice, instigated perhaps by the owners of horses, led to the enactment of laws that virtually ruled the automobile off the roads of England before the middle of the nineteenth century, and the vehicle did not gain a footing elsewhere un-

til the invention of rubber tires and the perfection of the gasoline engine had made possible the type of motor car that is making such universal appeal in our own day.

The case of the submarine boat is historically not dissimilar. Invented in Revolutionary days, it met with so cold a reception that almost a century elapsed before it made another conspicious bid for favor. Then, however, toward the close of the nineteenth century, its cause was espoused with fervor, in particular by the American inventor, Mr. John P. Holland, whose efforts are largely responsible for the development of the submerged craft as a practical war-machine. Another American, Mr. Simon Lake, has perfected submarine craft adapted not only for warlike uses, but also for the peaceful exploration of shallow water, salvage operations, and the like. Mr. Lake's submersibles are of "even-keel" type.

As recently as the time of the Spanish-American War, the authorities still looked askance at the anomalous vessel. But to-day submarines are as much a part of the equipment of a modern navy as are battleships. Submarines have been lowered to a depth of more than two hundred feet, where the pressure sustained was fifteen thousand tons. They have been navigated for forty consecutive hours without coming to the surface. Equipped with torpedoes they are instruments of naval war that not even the dreadnought can ignore; and the newest types are equipped with small cannon to operate at the surface, though their rôle in this position must obviously be subordinate.

THE DIRIGIBLE BALLOON

In the marine warfare of the future, the chief opponent of the submarine boat will be the dirigible balloon and the aeroplane, for these craft, from their coign of vantage, can detect the location of the submarine at its greatest depth.

The mere mention of these air-craft, as matter-of-fact antagonists of the submarine, suggests the marvelous change that has come about in the brief period since M. Santos Dumont astonished the world by driving a small balloon round the Eiffel Tower, on the 19th of October, 1901. It is matter of history that this was the feat that first convinced the sceptics of the feasibility of directing the flight of a balloon. A less convincing exhibition had been made a few months earlier at Lake Constance by the German military officer, Count von Zeppelin. But the voyage of Santos Dumont began and ended at the same place; whereas Count Zeppelin's balloon came to grief a little over three miles from its starting point.

The circuit of the Eiffel Tower demonstrated the possibility of directing the course of a balloon either across the wind or against it. But most people were skeptical as to any practical developments of so exceedingly clumsy an affair as a balloon; and only the more visionary would have predicted that in the course of a decade there would be scores of dirigible balloons in the air, some of them offering passenger service, and that every up-to-date nation would have its flotilla of airships of war.

The development of the dirigible balloon has been

very largely due to Count von Zeppelin, whose energies have led to the construction of one airship after another, and who is utterly undeterred by the repeated catastrophies that have overtaken his successive crafts. The flight of the Zeppelin III from Friedrichhafen on Lake Constance to Berlin and return in August and September, 1909, afforded a demonstration of the possibilities of aerial navigation that could not be ignored. The ship was destroyed a little later, to be sure; so were sundry of its successors, including the Deutschland I and Deutschland II. But disaster came while the ships were at anchor or near the earth; when in full flight the "Zeppelins" proved themselves craft of great stability and dependableness.

Equal praise must be given the balloons of a different type which have been developed by another German, Major von Parseval, and which bear his name. One of these has made regular trips out of Berlin and has a record of 4,000 miles without a single accident to its motors. The airship of Mr. Joseph Brücker, designed to cross the ocean, starting from the Cape Verde Islands, is of the Parseval type.

The Zeppelin and Parseval balloons may be considered the leading representatives of the two chief types of dirigibles. The essential difference is that the Zeppelin type of balloon has a rigid or semi-rigid framework of aluminum over which the air-tight casing of the balloon proper is stretched; whereas the Parseval type is without such a framework. In each case the balloon proper is composed of a series of disconnected gas-bag compartments. Both types of balloons are

driven by propellers not unlike those of a steamship (those of the Parseval, however, having canvas vanes), and depend for their dirigibility upon horizontal and vertical rudders, the former of which are not unlike the wings of an aeroplane.

The Parseval airship is supplied with an ingenious internal mechanism, which serves the double purpose of aiding in steering the ship and of compensating the loss of gas, which is always a serious item in a long voyage. This apparatus consists of two airbags or ballonets, within the main body of the balloon, capable of being independently filled with air or exhausted. If the forward ballonet is filled with air and the rear one deflated, the prow of the balloon is thereby made heavier and tends to head downward; and of course the conditions are reversed if the front ballonet is deflated and the rear one filled with air. If so much hydrogen is lost from the balloon that there is danger of collapse, both ballonets may be inflated and the loss thus compensated.

When it is recalled that air is about fifteen times heavier than hydrogen, it will be obvious that the air pumped into the ballonets serves as ballast. The use of air for this purpose seems to mark an important step in the art of aeronautics. The recognized form of ballast in the early day of ballooning was the sand bag. This serves a useful purpose in lightening the balloon, but the sand once thrown out obviously cannot be replaced. What is needed is a form of ballast that can be taken on or thrown out at will. In the day time the sun heats the gas bag and the balloon expands and tends to rise. At night the

gas cools and the balloon settles. It was to compensate this erratic tendency of the balloon that Mr. Wellman invented his much talked of equilibrator, consisting of gasoline tanks and blocks of wood arranged to trail in the water, and thus to add weight to the balloon when it tended to rise. The equilibrator proved a dangerous accessory, however, when it encountered heavy seas.

Mr. Vaniman, the chief engineer of Mr. Wellman's illfated trip, planned a new type of equilibrator which should dip up water when weight was needed and empty it when not needed. But such contrivances are clumsy at best, and it seems likely that the solution of the ballast problem must be looked for in quite another direction.

The air-chambers devised by Major Parseval (and which were adopted as accessories in both the Wellman and the Vaniman airships) afford at least a partial solution of the problem. Mr. Brücker planned to cool his airship in the daytime by spraying it. Other attempts to maintain the hydrogen at even temperature have utilized the plan of having a double-coated balloon with an air-chamber surrounding the gas-bag. Just before his death Vaniman attempted to solve the problem from the other point of view, by making the balloon-envelop strong enough to withstand the pressure of hydrogen expanding under influence of the sun's rays. Apparently any material stout enough to resist this pressure would prove much too unwieldy and heavy. But Vaniman's balloon exploded in its trial trip off the Jersey coast in 1912, the inventor himself and his companions falling to

their death. It is possible that the final solution of the gas-expansion problem may be found in a system of refrigeration pipes, similar to those used in cold-storage plants, or conversely in a system of ordinary hot-air pipes operated from the engine-room.

The most difficult problem that has confronted the makers of airships since the elementry principles of dirigibility were solved, has had to do not with the actual flight of the ship but with the safe landing of the craft. The cigar-shaped aircraft, with its thin shell of silk and rubber is obviously a frail structure. When not in use it must be housed in a tunnel-like shed. The sheds originally made at Lake Constance were stationary, and it was impossible to bring the airships out except when the wind blew almost directly in line of the long axis of the shed. Even a mild lateral wind would bring such pressure to bear as probably to break the airship in two. This, indeed, is precisely what happened to the British Naval airship "Mayfly" when it was being towed out of its shed for its maiden voyage.

The difficulty can be met by having the shed so constructed as to rotate on its axis, like a draw-bridge. The alternative is to have tracks extending from the mouth of the shed, on which the airship may be securely anchored and thus given complete rigidity before being run into the shed.

Of course the Germans have no monopoly in the building of airships. The French are close competitors, and their newest war-balloons, particularly those of the Clement-Bayard type (including the "Morning Post," which was built in France and piloted across

the Channel to England) are highly efficient. But the passenger service of the German dirigibles gives them particular interest. The equipment of the passenger coach of the two "Deutsclands" and their successor the "Schwaben," compares not unfavorably with that of a railway coach. The cabin has an aluminum frame lined with mahogany and rosewood and inlaid with mother-of-pearl. The cabin is about 35 feet long and 7½ feet wide, and divided into five apartments equipped with wicker chairs. The window openings are of course wide, so as to give an almost unobstructed view in all directions. There is room for 24 passengers and a crew of 8 men. The destruction of the Deutschland on its second trip, though unattended with loss of life, doubtless dampened the ardor of a good many would-be passengers; but the long series of safe passages achieved by the Schwaben and the Parseval ships has served to restore confidence, and there is every reason to suppose that the airships will grow in popularity.

The ships have proved themselves able to travel in all kinds of weather, and their speed compares favorably with that of the fastest ocean steamers. The Parseval ship "L. P. VI," for example, has a record of a trip from Munich to Berlin, a distance of 346 miles, at an average speed of 26 miles an hour. The Schwaben has three 145 horse-power motors, capable of driving the ship at a speed of about 35 miles an hour. Its carrying power is 20 tons at sea level.

It is rumored that similar airships are to be built for passenger service in America in the near future.

In any event, it seems reasonable to expect that not merely trans-continental but trans-atlantic airship service will be available within a few years.

Whatever may be the importance of such passenger service, however, it is not this possibility that accounts for the rapid development of the airship. The real spur to inventive ingenuity, accounting for the official interest in the airship so ardently manifested in Germany, France, and England, has to do with the possibilities of this craft as an agent not of peaceful commerce but of warfare. This accounts for the development of the "Society for the Study of Motor Aeronautics" in Germany, and for the recently opened "Deutsch Aero-Dynamic Institute" in Paris.

The possibility of launching a ton or two of dynamite from the safe heights of the upper atmsphere upon the deck of an enemy's ship or within the walls of his fortress, is the vision that inspires the European powers-that-be in their official aid to the development of the airship.

THE TRUE FLYING MACHINE

Even the most powerful dirigible is, after all, a floating apparatus rather than a true flying machine. It owes its buoyancy to the fact that it displaces more than its own weight of air; therefore it rises on the same principle that causes the rise of the child's toy balloon. In directing its course upward or downward, as well as laterally, the influence of guiding planes or rudders is of course necessary, and the propeller blades, driven by powerful gasoline engines, grip the air precisely as the propellers of a steamship

grip the water; so of course their propulsive power, combined with the adjustment of the guiding planes, gives the balloon a degree of stability in the air and of buoyancy that it would not otherwise have. Indeed in the case of the first successful dirigible of Santos Dumont, the buoyancy was almost entirely due to the propellers and horizontal rudders, the balloon with its passenger being only slightly less heavy than the air it displaced.

But it is obvious that a flying machine that must be lighter than air is necessarily of such bulk as to be unwieldy; and all along the ideal that inventors had set themselves was the perfection of a machine that would not be dependent on bulk for its buoyancy; one that could imitate the birds and bats in performing veritable flight in the air rather than merely floating, however accurately directed. In other words, the mechanism sought was a heavier-than-air machine that would fly.

In that first year of our new century, however, in which Santos Dumont achieved success with his marvelous dirigible, there were not many men of accredited scientific standing in the world who thought that this ideal would ever be attained. Indeed, there was only one famous scientist who was making conspicious efforts toward the practical realization of the ideal. This was Professor Samuel H. Langley of the Smithsonian Institution. Sir Hiram Maxim had indeed, performed some remarkable experiments a few years earlier, constructing a gigantic air machine, which, driven by propellers, lifted itself in the air and made a short flight stabilized by guid-

ing rods. But Langley attacked the problem from a different angle, and produced a model flying machine, with two pairs of canvas wings set tandem and having a spread of eleven feet, which, driven by a light motor of special construction, made a wonderful flight above the Potomac and settled to the water uninjured.

But Langley's larger flying machine, constructed on the model of his "aerodrome" plunged into the Potomac River in the attempt at launching, December 8, 1903. The inventor was heart-broken; and the entire public chorussed "I told you so," and gave the matter no further thought.

The entire public? Not quite; for among the seventy odd million of the American people there was an undistinguished minority of two individuals who differed from their fellows as to the feasibility of human flight. These two were Wilbur and Orville Wright, obscure bicycle dealers of the little town of Dayton, Ohio. While Maxim and Langley, each in his way, had been making strictly scientific experiments these young men, aided neither by private fortune nor public subsidy, had been devoting their spare time to experiments in gliding, following up the work of the ill-fated Lilienthal and of Messrs. Herring and Avery and Chanute.

They had invented a new type of bi-plane glider, and had learned to manipulate it with unexampled skill.

Finally they attached a gas engine and some wooden propellers to the glider, and on the 17th of December, 1903, little over a week after the final mishap to Langley's machine, they put their strange new craft

to the test. In the presence of accredited witnesses, with one of the inventors aboard, the weird contrivance lifted itself into the air, made a flight of 852 feet in the face of a twenty-mile wind, and landed its passenger in safety.

That day the aeroplane was born. The body of this wonderful mechanism consisted of two horizontal planes of canvas stretched over light wooden frames, with their long diameters adjusted transversely to the direction of flight, like the wings of a bird. The box kite had supplied the obvious model for the body of the aeroplane; and a gasoline motor driving two pairs of wooden propeller blades served to push the apparatus forward and virtually supplied a buoying air current comparable to that supplied the box kite by the wind. A kite cannot fly unless the wind has a certain strength; nor could the Wright aeroplane sustain itself in the air unless driven forward at a relatively high speed—not far from forty miles an hour. As originally operated, it received initial momentum from a catapult-like arrangement, and needed also the aid of the wind to help support it until it acquired full momentum. Once in the air, however, it attained a speed of forty or fifty miles an hour, and its course could be steered in any given direction regardless of the air currents.

A pair of horizontal rudders, originally placed in front of the main wings but it later models at the rear, provided for the vertical guidance of the apparatus; and a pair of vertical rudders at the back steered the machine to right or left.

An equally vital feature of the steering mechanism

was the fact that the main wings of the aeroplane were so constructed that their rear edges could be warped independently; thus varying the angle of incidence and hence the resistance to air pressure. By warping the edges of the right wings downward, those of the left wings remaining stationary, the machine would be made to tip to the left; the reverse warping would produce the opposite effect. A method was thus provided for meeting the disturbing influence of changing air currents and gusts of wind, which otherwise would overturn the machine. The vital importance of this feature of the mechanism is obvious.

But since the warping wings of the machine, while stabilizing it laterally, would tend to deflect it from its course, the apparatus was so arranged that a single lever controlled the flexible portion of the wings and the vertical rudders, the guidance of the latter counteracting the disturbing influence that would otherwise result from the twist of the wing tips. The discovery of this combination constituted the crowning achievement of the Wright brothers, and made their aeroplane a manageable mechanism. In other words, it made the flying machine a machine in which a man could fly.

All this was accomplished, as we have seen, in 1903. But for a time the Wright brothers did not take the public into their confidence, being chiefly concerned in interesting our government in the aeroplane as an auxiliary instrument of war, and it was not until 1906 that the details as to the principles of the wonderful aeroplane were accessible through Pat-

ent Office specifications. Then a host of imitators set to work devising air craft of many patterns. Some of these are to casual observation very different from the Wright machine; in particular the monoplanes, of which M. Blériot's is the best known. But in their principles of operation all aeroplanes yet devised are indentical. No machine has yet carried a passenger in safety that did not depend for its stability upon warped wings or their equivalent, combined with the use of vertical and horizontal rudders. Details aside, all aeroplanes thus far invented are Wright aeroplanes.

It is worth while to emphasize this point, because attempts are constantly made to becloud the issue. It has been urged that the Wrights were not absolutely the first users of any one of the devices that they combined to make their aeroplane. They did not invent the canvas planes or the vertical or horizontal rudders or the warping wings or the motor. Very true; but they used them first in successful combination, producing for the first time in history a flying machine heavier than air that would fly and carry a passenger, and go where directed and land in safety. Their title as inventors of the aeroplane is far clearer than the titles of the accredited inventors of the steamship, the steam locomotive, or the telegraph.

So the 17th of December, 1903, must stand out as one of the memorable dates in the history of civilization. And there is every reason to believe that in the remote stretches of the future the names of Wilbur and Orville Wright will be remembered when the

bulk of the names that now loom large in our generation are utterly forgotten.

HIGH FLYING

The more recent history of the development of the art of flying is a matter of common knowledge. But it may be of interest to recall a few specific achievements.

On the 17th day of September, 1912, a French aviator, M. Georges Legagneaux, soared into the air in his monoplane, and in the course of three-quarters of an hour had attained the dizzy height of three and a half miles; or, to be more precisely accurate, 5,720 meters, or 18,761.60 feet. The accomplishment gained wide attention, because it constituted a record; yet it can scarcely be said to have occasioned surprise, for after all it exceeded a record made ten days before by M. Garros by only about 2500 feet. Meantime another aviator had gone to the height of 13,000 feet carrying a passenger; and yet another had piloted two passengers more than a mile and a half into the air. Moreover the record made by Legagneaux was surpassed by Garros, who attained 18,400 feet at Tunis, on December 11th; and this record in turn gave way to one established by M. Perreyon in France on March 11, 1913, the new record being 19,685 feet or almost three and three quarter miles. It is thought that the limit has nearly been reached with motors of the present type, as the air at this great height becomes so thin as to reduce greatly the lifting power of the aeroplane and the horse power of the motor. The great cold makes

the feat difficult for the aviator, and it is usually necessary to inspire oxygen carried in a tank. All in all, the feat of bestriding a ton of steel and canvas and lifting the unwieldy hulk above the clouds seems little less than miraculous.

A high record of another type was gained (also in France) by Pierre Gougenheim in piloting an eighty horse power biplane carrying four additional passengers to the height of 2461 feet. The feat was accomplished in a heavy wind, and a greater altitude would have been reached but for a shower.

In September, 1913, M. Pegoud twice performed the astonishing feat of voluntarily describing a letter S in the air, flying upside down for several hundred yards in so doing.

The speed possibilities of the aeroplane are suggested by the 105.5 miles an hour made by Jules Vedrines at Chicago in 1912 over a course of 124.8 miles, in a 140 horse power monoplane. In the matter of endurance flights and long distance journeys through the air there are new records almost weekly. One aviator has flown from the Atlantic to the Pacific; another has gone from Paris to St. Petersburgh; and the flight from Paris to London is almost commonplace. In June, 1913, M. des Moulinais made a 933-mile flight from Paris to Warsaw, his time in the air being ten hours, and his average speed, 93 miles an hour. M. Guillaux flew 859¾ miles in a day; and, on September 15th, 1913, with a pessenger, 118 miles in fifty minutes. M. Letorl flew 590 miles without a stop; and in America Mr. C. M. Wood made on August 8th, 1913 a nonstop flight

from Hempstead, Long Island to Fort Meyer, a distance of 329 miles, in 4 hours and 31 minutes.

THE HYDROAEROPLANE

But all these are matters of detail. The only really essential modifications of the aeroplane in the first decade of its existence relate to the methods of starting and landing. The first modification, which was introduced early by European aviators, notably Mr. Henry Farman, and which was soon universally adopted, consists of adjusting bicycle wheels to the frame of the machine. A still more striking modification depends upon an arrangement designed to permit the aeroplane to rise from and alight on the water. The development of this idea has resulted in the so-called hydroaeroplane.

The advantages of this type of air craft are obvious. They were pointed out by Octave Chanute, a pioneer in the use of soaring apparatus, in the early days of experimental aviation. Langley made his experiments over water courses, as did Hargreaves, Blériot, and Kress. But Fabre in France seems to have been the first to succeed in making a machine that would rise from the water. Mr. Glenn H. Curtiss, the American aviator, has been prominent in perfecting the apparatus. It should not be overlooked that a clue was given by Wilbur Wright when he made his historic flight up the Hudson in 1909; his aeroplane on that occasion being equipped with a covered canoe, to give it safety in the event of an inadvertent descent into the river.

The hydroaeroplane is simply a combination of

UPPER FIGURE: THE FARMAN HYDROAEROPLANE
LOWER FIGURE: A FRENCH FLYING-BOAT

boat and flying-machine. But the boat must be of such shape that it will skim through the water with the least possible resistance, and equipped with a powerful motor.

At the present time two types of hydroaeroplanes are popular, one of which might be described as a flying-machine with floats, the other as a boat with wings. In the first of these, the floats, two in number, are in the form of a catamaran, the operator occupying a seat in the same position as on the aeroplane. In the other, the single hull serves as a seat for the operator as well as a float, and the craft, if shorn of its wings, would resemble the racing type of motorboat. These single hull hydroaeroplanes are kept from capsizing by small auxiliary floats placed beneath the tips of the wings, and it is claimed by the advocates of this type that it has manifest advantages over the catamaran in rising more readily from rough water.

PRACTICAL USES OF THE AEROPLANE

As yet little practical use has been found for the aeroplane except in military and naval operations. But in these it is proving revolutionary. Thus far its success has lain largely in the field of scouting—one of the most important features of military maneuvers. How successful the army scouts have proved themselves is shown by the fact that in England the autumn army maneuvers of 1912 were terminated because the movements of the opposing armies could not be concealed from the airmen, and the commanders found the hitherto accepted tactics impractical.

Thus, as "the eyes of the army," the aeroplane, equipped with wireless telegraph apparatus, has proved its value.

But the aeroplane is making rapid progress as a fighting-machine as well. In August, 1912, Lieut. Scott, an American, won the Michelin Target Competitions in France, by dropping twelve out of fifteen bombs into a circle of 66 feet in diameter from a height of 656 feet. This performance would seem to place the aeroplane in the position of a destructive agent that must be reckoned with. Indeed, armies of all nations are making such a reckoning.

Four classes of bombs have been designed for these aerial fighters: (1) heavy explosive bombs, to be used against ships, dockyards, railways, bridges, and buildings; (2) small bombs or hand-grenades, for troops assembled in masses; (3) incendiary projectiles, for destroying buildings or magazines; (4) metal projectiles, for attacking air-craft.

Meanwhile the armies and navies of the world are busy with designs of guns for destroying aeroplanes and dirigibles; and Col. Isaac N. Lewis, of the United States Army, has perfected an automatic gun which may be used from the airship, or against it. This gun, which fires at the maximum rate of 750 shots a minute, weighs only twenty-five pounds, and is air-cooled. It was designed primarily for the use of cavalry and infantry, for which it is admirably adapted, but its unique features make it peculiarly useful as an aerial weapon.

This gun was tested in June, 1912, and from a height of 600 feet placed forty-five shots in a space

FRENCH HYDROAEROPLANES OF MONOPLANE AND BIPLANE TYPES

three yards by eighteen while the aeroplane was moving at a rate of fifty miles an hour. The bullets used are the regulation 30-caliber used by the army.

It remains to be seen what practical uses may be found for the aeroplane in solving transportation problems of the future. Such a flight as that made in August, 1913, by Mr. Harry G. Hawker in his hydroaeroplane flight around the British coast, in which he covered 1043 miles in about as many minutes' flying time, carrying a passenger and making 494 miles in his best day's journey, suggests practical uses for the aeroplane, and particularly for the hydroaeroplane, that as yet are almost untested.

THE WIRELESS TELEGRAPH

In rounding out this brief survey of the triumphs of science in overcoming the barriers of time and space, there remains for notice perhaps the most mystifying achievement of all, the invention of the wireless telegraph. This might be called a conquest not merely of the air, but of the ether. And it has the double merit of being a scientific achievement which has obvious elements of the utmost practicality.

As evidence of the interest that attaches to the achievement as a fundamental investigation in science, it may be noted that the Nobel prize in physics was given in 1900 to Signor G. Marconi and Professor Ferdinand Braun in recognition of their contributions to the perfection of the wireless telegraph. As evidence of the practical character of the achievement, it suffices to recall that every large ocean liner is now equipped with its wireless apparatus, and that the

Marconi service is in active competition with the transatlantic cables in sending news from one continent to another.

To the American public Professor Braun's name is by no means so familiar as Signor Marconi's, but the wireless system of the former is very generally used in Germany, and is also extensively used in the American army. Neither of the distinguished men in question is the original discoverer of the method of transmitting messages through the air, but they were among the most prominent developers of the method. To Marconi unquestionably belongs the honor of sending the first message across the ocean. This transcendent faet was accomplished on the 12th of December, 1901, a single letter being signalled repeatedly on that day. Complete messages were first sent December 21, 1902.

Had the great German physicist Hertz been living, it is probable that he would have been named along with the two inventors of the wireless in connection with the Nobel prize. For it was his investigation that gave the clue to the practical work of his successors. Even before Hertz made his demonstration of the electro-magnetic waves that are used in sending the wireless messages, the great Englishman, Clerk Maxwell, had theoretically shown the existence of such waves in connection with his electro-magnetic theory of light. But the tangible demonstration was made by Hertz through the development of a very rapidly oscillating current of electricity which generates measurable waves in the ether.

In all probability these waves differ in no wise

from the ether waves that we interpret as light except in their length, but in this regard the difference is enormous. The longest wave that is visible to the eye is of such infinitesimal dimensions that 33,000 waves are required to span the distance of a single inch. But the electro-magnetic wave with which the wireless operator deals may measure scores or hundreds of miles. Suppose, for example, that the electric current generating the wave oscillates at intervals of the one thousandth of a second. Then, since the wave travels 186,000 miles per second, each wave will obviously be 186 miles in length. In practice, the waves used in transatlantic radiography are between two and three miles in length.

Such a discrepancy in size being noted, it is not surprising that the electro-magnetic waves used by the wireless have a penetrating power altogether different from that of the tiny light waves. In point of fact the waves that transmit the wireless messages penetrate any substance that lies in their path, including mountains. Curiously enough, bright sunlight may obstruct the waves, presumably because of the presence of electrons in the atmosphere.

The possibilities of wireless communication had been conceived by many experimenters. As long ago as 1887 Mr. Thomas Edison proved that messages could be sent to and from a moving train, communication being established through the air between the operator on the train and the ordinary telegraph wires along the track. By various other experimenters the possibility of communication without wire was considered and more clearly demon-

strated. The methods involved as outlined by Professor J. A. Fleming, included electrical conduction through soil or sea; magnetic induction through space; a combination of these methods, and electrostatic induction. But after Hertz made his famous demonstration with electric waves, it became apparent that this form of radiation offered possibilities surpassing all others.

Two great difficulties confronted the experimenters: the production of electric waves of great power, and the detection of the waves at a distance. The first important clue to a practical method of detecting the waves was given by the Frenchman Branly, who showed in 1890 that a loose metallic powder is changed from a poor to a good conductor by the influence of the Hertzian waves. Sir Oliver Lodge extended the experiments along this line and in 1894 exhibited a little apparatus which he called a coherer, which consisted essentially of metallic filings in a tube connected with an electric circuit. These filings, loosely arranged, resist the passage of eletricity; but when influenced by Hertzian waves, sent through the air from a distance, the filings "cohere" and readily permit the passage of the electric current. A tap on the tube restores the filings to their original condition of non-conductivity.

Sir William Crookes, as early as 1892, suggested that Branly's discovery regarding the metal filings might be utilized in the sending of wireless telegraphic messages. But no one showed practically how this might be effected until Signor Marconi began his investigations. In 1896 Marconi had per-

fected an improved coherer, which consisted of a glass tube four millimeters in diameter with two silver plugs connected with the wires of an electric battery but separated within the tube by an interspace of about one millimeter, this space being partly filled with metallic filings, 5 per cent. silver and 95 per cent. nickel. Marconi had discovered that if his coherer had "one terminal attached to a metallic plate, lying on the earth, or buried in it, and the other to the insulated plate above the ground, it would detect the presence of very feeble electric waves."

He had also discovered that he could advantageously produce electric waves of great carrying power by the use of a large induction or spark coil with spark balls placed a few millimeters apart, one ball being connected with the earth plate and the other with plates or wires insulated at the upper end and raised into the air. He put the apparatus in operation with the aid of an ordinary telegraphic signalling key placed in the primary circuit of the induction coil. When the key was pressed there was a rush of electric sparks between the balls alternately charging and discharging the elevated conducting wires and creating electrical oscillations. The longer or shorter pressure of the key varied the action of this transmitter making possible the use of the regular Morse code.

Electric waves sent out by such a transmitter radiate into space, and their sequence of emission in longer or shorter series in response to the pressure of the telegraph key, is recorded by the receptive

coherer, which, as we have seen, transmits the electric current of its own circuit only while the Hertzian waves beat upon it, and which is automatically restored to its condition of non-conductivity by the apparatus that taps gently against the tube.

Such was the essential character of the apparatus through which Signor Marconi made his conquest of the ether. The modifications that have since been made pertain to the production of more powerful transmitters on one hand and more sensitive receivers on the other. They include partially successful attempts to send the electric waves in a desired direction; and magnetic receivers of greater sensitiveness than the metal filing coherer. The most striking amplification of the method, however, is the attempt to adapt the apparatus to the transmission of the human voice; to perfect, in other words, a wireless telephone.

In this effort a large measure of success has been attained, in particular by the American, Dr. Lee De Forest, who in 1907 perfected an instrument with which he could transmit the music of a phonograph between stations situated in different city blocks. A few weeks later he was able to report by voice the results of yacht races at a distance of about four miles. In the autumn of the same year his instruments were installed on the American fleet of war vessels on their trip round the globe, and kept the vessels in verbal communication with each other, in storm and calm, during the entire voyage. A year later it was reported that messages had been sent and received at a distance of over 500 miles, and that a

practical working service between Chicago and Milwaukee had been put into operation. Nevertheless the wireless telephone has not made its way as a commercial mechanism as rapidly as might have been anticipated.

AUDIBLE LIGHT

The impulse that comes by wireless, like that which flashes over the telegraph wire, is only a pulsing of energy that in itself conveys no definite message except as it is broken into longer and shorter relays, so to speak, in the familiar sequence of the Morse alphabet, or is translated into sound-waves by the telephone receiver. It is wonderful enough in all reason, that these impulses can be translated into words; but this is not quite the ultimate achievement at which the inventor aims. Ever since the telegraph was devised, and in particular since the invention of the telephone, men have dreamed of the possibility of doing for the eye what the electric current does for the ear; in other words, they have sought a means of transmitting visible as well as audible messages.

An inkling of the curious possibilities of interchanging sight and hearing is given by an apparatus recently devised by an imaginative English physicist, Dr. Fournier d'Albe: an apparatus that enables a blind man to distinguish between light and darkness, and even under certain circumstances to recognize the presence of opaque objects at a distance. In a recent public test of the apparatus, a blind man standing in the center of a room was able to count the

windows in the room, and to number the people who stood between him and the windows. He utilized the sense of hearing, yet the apparatus used depended on the influence of light. Hence the experiments have been picturesquely, if not quite accurately, referred to as making light audible.

The apparatus employed, to which the inventor has given the name optophone, is essentially a telephone into the circuit of which a cell of the curious element selenium has been introduced. This substance has the peculiar property of being very resistant to the passage of the electric current when in the dark, and of transmitting it readily in the light. The optophone is so constructed that the selenium cell is screened from the light except as admitted through a narrow tube. When this tube is directed toward the light, the current passes, and the holder of the telephone hears a buzzing or whirring sound. But when the tube is directed toward a dark object, the current is obstructed, and the sound in the receiver ceases or is weakened.

This explains how the blind man, by sweeping the tube slowly about, could detect the presence of here and there a human being. The apparatus has not yet been sufficiently perfected to enable the blind man to detect chairs or other small pieces of furniture but it is hoped that a practical apparatus serving this purpose, and having great utility for the blind, will eventually be developed along the lines of the optophone.

The curious element used in the interesting apparatus was referred to in a cabled newspaper despatch not long ago as "a rare radioactive substance, re-

cently discovered by Mme. Curie." In point of fact, selenium is neither radioactive nor of recent discovery. Moreover it is not a rare element. It is widely distributed in nature, but occurs in small quantities. It was discovered and named by the famous Swedish chemist Berzelius, as long ago as 1817. The word selenium is from *selenus*, the Greek name for the moon, and was given because the element is usually found associated with tellurium (from *tellurus*, earth); a fanciful association of ideas characteristic of the imaginative mind of the discoverer, who was one of the fathers of modern chemistry.

While Dr. d'Albe's optophone is novel and spectacular in its precise accomplishment, it depends upon a principle that has previously been utilized in the construction of several interesting mechanisms. The fact that selenium conducts electricity only in the light was discovered by a Mr. May and confirmed and reported by Willoughby Smith, telegraph operators at Valencia, as long ago as 1873. It was at once surmised that interesting applications of the anomalous fact might in time be made. Some illustrations of the possibilities were given by Mr. Wm. J. Hammer before the American Institute of Electrical Engineers in New York. Mr. Hammer fired a cannon over the heads of the audience by throwing a beam of light from a distance; and he operated a five horse power dynamo, alternately starting and stopping it at will, merely by waving his hand across a beam of light directed toward a selenium cell introduced in the electric circuit.

Mr. Hammer suggested that the cannon of a fort

U.T.C. Library

might be so arranged in time of war that the search light of a hostile ship would discharge the weapon just at the moment when it was so directed as to send its missile to the ship furnishing the source of light. He suggested also that selenium cells might be arranged in such a way as to make possible direct vision over a telephone wire;—not the mere sending of pictures, but actual vision of objects, as, for example, the face of the talker at the other end of the wire. But whatever the possibilities in this direction, no such instrument has yet reached the commercial stage.

PHOTOGRAPHS BY WIRE AND BY WIRELESS

Meantime the curious property of selenium has been utilized in a very ingenious manner in the development of a system of sending pictures by electric wire, the originator of the method being Professor Korn, now of Berlin. The apparatus that he devised was put into practical use as long ago as November, 1907, for the telegraphic transmission of pictures from Paris to a London newspaper; and Professor Korn is now perfecting apparatus with a view of transmitting photographs from New York to London.

The essentials of the process consist of wrapping a photograph made on celluloid about a glass cylinder, and revolving the cylinder in such a way that the focussed beam of a Nernst electric lamp penetrates the successive portions of the photograph, in a spiral path that finally takes in the entire cylinder, just as the needle of an Edison phonograph traverses the close spiral constituting the phonograph record.

It is obvious that as the beam of light passes over successive portions of the transparent photograph, the intensity of the transmitted light will vary constantly with the tone of the photograph itself. The high lights of the photograph will be represented by blank spaces on the celluloid that will not obscure the light at all; whereas the deepest shadows will obstruct it altogether; and the middle tones will transmit light of varying intensity.

All this is a simple matter of physics having nothing to do with electricity or with selenium. The agency of the latter is invoked when the constantly varying beam of light transmitted to the interior of the glass cylinder is reflected by a prism in such a way as to fall on a plate of selenium introduced in the telegraphic circuit. As the intensity of the light constantly fluctuates, the current of electricity transmitted through the selenium fluctuates correspondingly; and this oscillation in the electric current is recorded at the other end of the line, with the aid of another selenium plate and prism, by a beam of light acting on a receiving drum covered with a sensitive photographic film and exactly indentical in size and rate of revolution with the glass cylinder of the sending instrument.

The photograph printed on the receiving cylinder shows a nice gradation of lights and shadows and is a relatively close copy of the original. When closely examined, however, it will appear that the new photograph is composed of parallel lines, which widen or grow thin according to the density of the picture. These lines represent the original spiral which, now

that the picture is removed from the cylinder and laid flat, appear as parallel lines drawn across the picture. It is obvious that the closeness of the spiral will determine the degree of accuracy with which the tones of the original are reproduced.

Although this system of tarnsmitting pictures proved a commercial practicality, it early occurred to Professor Korn that he could improve upon it for commercial purposes by a method which retained the cylinders, but operated otherwise in a quite different manner. The new method utilizes an apparatus which Professor Korn calls a telautograph. It was further improved by Mr. T. Thorne Baker of London, whose perfected instrument is called a telectograph. This instrument makes no use of selenium, and the principle upon which it works is not that of a fluctuating but of an interrupted current.

The picture to be transmitted must now be composed of lines, like a pen drawing, or of dots, as in case of a half tone. The picture is printed with some non-conducting substance such as fish-glue on a thin sheet of lead, and this is wrapped about a cylinder as in the other apparatus. A point of metal connected with the transmitting electric wire is arranged to touch the cylinder and traverse it in a spiral as the cylinder revolves, precisely as the needle of the Edison phonograph traverses the cylindrical record. As the metallic point passes over dots or lines on the picture, the current is interrupted; but contrariwise the current is transmitted when the point comes in contact with the lead surface, which represents the high lights of the picture.

At the other end of the circuit the picture is reproduced on a sensitized paper wrapped about a cylinder, which is traversed spirally by a platinum point connected with the electric circuit. When the current is transmitted, it discolors the sensitized paper, through exciting chemical action; when the current is broken the paper remains unchanged. So the net result is the tracing on the receiving drum of a series of dots or short streaks which pass in a close spiral about the cylinder and thus build up the picture.

The fidelity of the reproduction will depend as before on the closeness of the spiral and the accuracy with which the receiving drum corresponds in speed of rotation to the transmitting drum.

In practice the drums are rotated at a speed of about thirty revolutions per minute, and the apparatus operates with such speed as to record three hundred sharply defined chemical marks per second. Accordingly a picture of considerable size may be built up by the endless spiral of graduated marks in the course of a few minutes. Stated otherwise only a few minutes are required to transmit a picture of whatever degree of complexity from sending to receiving station, as for example, from Paris to London.

Mr. Baker's telectograph system, which has been in practical operation between Paris and London and between Manchester and London, has additional interest in that it can be operated in connection with a wireless apparatus. As yet pictures have not been sent to a very great distance by wireless, but Mr. Baker predicts that wireless transmission of photographs may eventually prove of more utility than the

other method, because it would bring America within reach of Europe and would enable communication to be made where telephone or telegraph wires do not exist. "It is not limited to photographs—banking signatures, sketches, maps, plans, and writing could be transmitted."

Mr. Baker was careful to point out, in an address on the subject before the Royal Institution of Great Britain, that the system of transmitting photographs by wireless is yet in the very early stages; he predicts, however, that advance toward perfection of the method will be so rapid that what is said about it now will within a few years have only a curious historical interest. But even as the matter stands, the wireless transmission of pictures may be regarded as almost the culminating marvel of an age of marvels.

XI

OUR WONDERFUL GENERATION

ONE day in September, 1912, it was announced that the military maneuvers of the British Army had come to an abrupt and unexpected termination because they were rendered farcical by the airmen scouts. Secret maneuvering was impossible for either side.

A few days later Count Zeppelin sailed casually forth from Berlin in one of his new dirigible balloons and appeared presently hovering over Copenhagen. He alighted, paid a formal visit to the authorities, and arose and sailed away. It was a peaceful visit, yet the navigator had been enjoined not to direct his craft over any fortress or warship. But what if the visit had been warlike, the craft laden with bombs, and the forts and warships its chief object of attention?

At about the time when these things were happening in Europe, a great body of men of science gathered in New York to attend the sessions of the Eighth International Congress of Applied Chemistry. These are the men whose labors link the laboratory with the workshop. If the full story of their efforts of recent years were told, there would be revealed a record of revolutions in half a score of important

industries, involving tens of millions of dollars of invested capital.

Suffice it for the moment to name among the accomplishments of these practical chemists in recent years: (1) the synthesis from coal-tar products of artificial dyes, pigments, and perfumes in endless profusion, revolutionizing the indigo and madder industries; (2) the manufacture of synthetic pearls and rubies and allied gems, forecasting a readjustment of the profession of the jeweler; (3) the making of carborundum, harder than any natural abrasive but the diamond, and of graphite purer than any ever mined; (4) the transformation of vegetable fibre into an artificial silk in some respects outrivaling the natural, 15,000,000 pounds of which are now annually put on the market; (5) the taking of nitrogen from the inexhaustible storehouse of the air, to form ammonia and nitric acid, the basis of numberless industrial compounds, including fertilizers indispensable to our agricultural fields; and (6) the very recent synthesis of pure rubber out of starch, an accomplishment the industrial importance of which will probably be manifest in the near future.

Scarcely had the papers ceased to chronicle the doings of the Industrial Chemists when they were called upon to record the proceedings of another body of practical scientists, the Fifteenth International Congress on Hygiene and Demography, meeting in Washington. President Taft remarked facetiously, in an address of welcome, that he had been too busy to learn the meaning of the word demography, but that we all know what hygiene means

and that we are begining to appreciate its importance. That the country at large did appreciate the importance of the topics discussed was evident from the space given the proceedings in the daily press. And the interest was well merited, for the discussions had to do with such topics as the prevention of disease, the reduction of infant mortality, the lessening of insanity, and the prolongation of human life in general.

THE NOBEL PRIZE WINNERS

Such illustrations show why ours has been termed a practical age. But we need not look far afield to discover that the devotees of theoretical science have been no less busy and no less successful. On the 10th of December each year a little company of men assemble in Stockholm to receive the Nobel prizes in Science, of which everyone has heard. The annual prizes in Science, each carrying an honorarium of about $40,000, are awarded for notable achievements in Physics, Chemistry, Physiology, and Medicine. With a few notable exceptions, the recipients of these prizes have been workers in pure science; and the results of their investigations constitute a most remarkable body of new knowledge.

The discoveries recognized include the X-ray, which founded an entirely new department of science; radium and its allies, which founded another; the law of osmosis, with its fundamental explanation of the phenomena of liquids; the ion-chemistry, which carries us to the very heart of the atomic world; the electron, or unit particle of electricity, which reveals

a something 1700 times smaller than the hydrogen atom; the proof that light is a form of electromagnetism; five new gases in the atmosphere; the exact measurement of light-waves, to the millionth of an inch; the proof that carbon can be transformed into diamond in the electric arc; the explanation of the manner of brain cell activity that underlies the processes of thought; explanations of world-building based on a new theory of light-pressure; and sundry analyses of the chemical properties of living matter that cannot be characterized in a phrase.

If to this list of achievements in theoretical science we add such practical accomplishments as the perfection of the wireless telegraph; the development of antitoxin, tuberculin, and the Finsen ray; new studies of digestive and assimilative processes; explanations of the mechanism through which the body fights disease; and the transplanting of living organs, we shall gain at least an inkling of the wide scope of the new knowledge, as recognized by the Nobel Foundation.

It may well be doubted whether any single generation of the past ever witnessed such rapid progress in so many fields of knowledge or the development of so many brand-new ideas in theoretical science as have come to light in this age.

SEVEN WONDERS OF THE MODERN WORLD

Let me cite now another illustration of the remarkable character of present-day achievements. Every one has heard of the seven wonders of antiquity, and most readers will recall that the pyramids

of Egypt, the hanging gardens of Babylon, the temple of Diana at Ephesus, and the Colossus of Rhodes were among them. The others were the Pharos of Alexandria, which was a light house 400 feet high, the statue of Jupiter by Phidias in the Parthenon at Athens, and the mausoleum of Artemesia. All of these so-called wonders, then, were examples of engineering or architectural skill or of art on a colossal scale.

In our day gigantic engineering and architectural enterprises have become so common that their results have for the most part ceased to cause wonder. In other directions, however, the scientific workers of our time have produced results which excite the astonishment even of the initiated, and many of which are brought constantly to the attention of the man in the street as well. The publishers of "Popular Mechanics" recently desired to ascertain which among modern achievements are best entitled, in the opinion of experts, to rank as the seven most remarkable of present-day wonders. Therefore, they made out a list including 56 discoveries or inventions of modern times, all of which might properly be described as wonderful. The list was comprehensive in its scope, including the results of great engineering efforts such as the Simplon Tunnel, the Catskill Aqueduct, Subway Transportation, and the Panama Canal at one end of the scale, and such achievements of theoretical science as have to do with ultra-violet rays, the ultra-microscope, and synthetic chemistry at the other.

This comprehensive list of modern achievements

was sent out to 1000 eminent men in Europe and America, including members of the French Academy of Science, the Royal Society of London, the great German Universities, the American Academy of Science, and various famous men of science in private life. The request was made that each would mark off on the list of 56 subjects the seven that seemed to him to represent the most wonderful modern achievements. It is reported that about 700 of the scientists responded. The result of their balloting is not definitive, of course, but it has obvious interest. It presents seven modern wonders in the following order: (1) the wireless telegraph; (2) the telephone; (3) the aeroplane; (4) radium; (5) antiseptics and antitoxins; (6) spectrum analysis; (7) the X-Ray. The three next most popular "wonders," making up a total list of ten, were in succession, (8) the Panama Canal, (9) anaesthesia, and (10) synthetic chemistry. The last named of these may fairly be considered too vague and general a subject to be rightly listed with the other specific achievements.

Of the seven chief "wonders," all but one are entirely familiar to the general public as to their main developments. The exception is spectrum analysis, which is less familiar partly, perhaps, for the rather paradoxical reason that it has been longest in evidence. The first efforts at spectrum analysis were made about the middle of the nineteenth century, and the spectroscope was applied to the analysis of the composition of stars about fifty years ago. The perfected instrument, however, is of much more recent development, and its feat of measuring the flight

ANÆSTHESIA AND ASEPTIC SURGERY

of stars and testing their chemical composition has failed to attract wide popular interest chiefly because it deals with subjects so remote from every-day life.

Of the remaining six modern wonders, the telephone dates from about the year 1876, and the initial use of antiseptics is but a few years older. Wireless telegraphy, the aeroplane, radium, the anti-toxins, and the X-Ray have all seen their entire development since 1895. No doubt their extreme newness accounts in part for their selection, for of course things seem wonderful somewhat in proportion as they are novel; but on the other hand we can hardly doubt that each of these strictly up-to-date discoveries and mechanisms will continue to hold high rank among the things accounted extraordinary in coming generations.

That such a list can be presented of achievements of any given generation is altogether remarkable. No one who considers this aspect of the subject can doubt that our age is one of the most extraordinary in all history. To the American it must be gratifying to observe that the second and third among the "wonders" selected by this international jury (the telephone and the aeroplane namely) were invented on this side of the water. Moreover, if the list is extended to include nine subjects, two more American achievements are included, the Panama Canal and anaethesia.

ACHIEVING THE IMPOSSIBLE

There is yet another list of remarkable recent achievements that I wish to cite, because it takes

note of some accomplishments that are not named in any of the lists already given. The German publication "Prometheüs" celebrated its twenty-fifth anniversary in 1912, and the editor, Professor Witt, was led to comment on the changes in the world of science that have taken place in the quarter century since the journal was founded. He pointed out that a number of the chief quests of the workers of twenty-five years ago, which then seemed almost hopeless of solution, have been triumphantly achieved.

As cases in point he named the following: (1) the dirigible balloon, (2) the aeroplane, (3) the submarine boat, (4) the attainment of the North Pole (had he written a few months later, he might have included the South Pole also) and the absolute zero of temperature, the latter approached within a little over one degree, (5) wireless telegraphy, (6) the transmission of photographs by wire, and (7) color photography. It is curious to note that of the seven "wonders" named here, only two duplicate citations of the other list,—so wide is the opportunity for selection.

THE NEW ERA

Were we now to collate the diverse summaries, making allowance for duplications, we should find in the various lists cited more than thirty very notable scientific achievements any one of which by itself would give a certain distinction to an epoch. It has been the purpose of this book to give some details regarding the development of many—but by no

means all—of the remarkable achievements here listed. They are recapitulated here in epitome chiefly by way of summary, but also to name a few accomplishments that for one reason or another have not fallen within the scope of our present inquiry.

And now, in concluding a summary which explicitly disclaims any attempt at completeness, I perhaps cannot do better than to apply to the foregoing pages the words with which I closed a chapter in a volume of my work on *The Wonders of Science in Modern Life*, of which chapter the present volume might be said to be an amplification. I make the quotation with slight adaptations to apply to the volume in hand:

"Let it be noted that the most ancient of the discoveries with which we have dealt date from about the middle of the last decade of the nineteenth century. In other words, the period involved is only about eighteen years. Indeed the great body of revolutionary accomplishments in question were brought to light within the space of the single decade 1895-1904. It is startling to reflect on the number of new ideas that were added to the sum total of human knowledge in that period.

"Let us recall, by way of illustration, that two of the most learned and most versatile men of science of the nineteenth century, John Tyndall and Thomas Henry Huxley, died respectively in 1893 and 1895. The time is so recent that the names of these men have not ceased to be household words. Yet if these two men, whose joint knowledge covered every field of physical and biological science, could come back

to us to-day they would find themselves unable to comprehend the very phraseology in which even a rudimentary lesson in science might be given in a college classroom.

"Such words as X-Ray, radium, radioactivity, electron, Zeeman effect, Mendelism, serum-therapy, salvarsan, Finsen ray, argon, krypton, neon, aeroplane, radiograph, ultra-microscope, and the like would have for them absolutely no meaning. They would have but vague notions as to what dirigible balloons might be like. Diesel engines, vaccine therapy, the meteoritic hypothesis, carborundum, the side-chain theory, anaphylaxis, unit characters, dominant and recessive traits, eugenics,—all these would be unmeaning terms, or terms quite lacking their present-day significance. The entire coterie of new sciences associated with these words—supplemented in each case by a more or less elaborate terminology of allied words—has sprung into being in the brief interval that has elapsed since these great expositors of nineteenth century science died.

"In no other way, perhaps, could we make more vividly manifest the extraordinary progress of our new era than by reflecting on the great variety of subjects, now matters of common knowledge, about which Huxley and Tyndall knew nothing."

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